Whole Building Life Cycle Assessment: Neville Scarfe Building

Aaron Mahiban

University of British Columbia

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This study is part of a larger study – the UBC LCA Project – which is continually developing. As such the findings contained in this report should be considered preliminary as there may have been subsequent refinements since the initial posting of this report.

If further information is required or if you would like to include details from this study in your research please contact rob.sianchuk@gmail.com.

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Abstract

This report details a life cycle assessment conducted for the Neville Scarfe building at the University of British Columbia. The portion of the building studied was built in 1961 and is a concrete building with suspended slab floors throughout. The main function of the building is classroom oriented space, however it also includes a staff lounge, a student lounge and a large lecture theater.

The material takeoffs for this study were conducted using OnCenter's Onscreen Takeoff program. Relevant drawings for the building were imported into Onscreen Takeoff as PDF files, to be used for measuring specific dimensions. Once the quantity takeoffs were completed, the amount of each material was entered into Athena's Impact Estimator software. Referencing an LCI database, this program gave a summary of a number of environmental impacts embodied within the manufacturing and construction of the Scarfe building.

The total primary energy required for the construction of the building was 192.6 Mega Joules per square foot of academic building space. It was also determined that the building's concrete content played the largest role in its environmental impacts. By increasing the volume of concrete by 10%, an average increase of 6% for all measured impacts was observed. Furthermore, it was determined that by bringing the Scarfe building's insulation up to current standards, the energy savings would surpass the upgrade's embodied energy in less than two years.

This study found that while the Scarfe building was built to the standard of the day, it falls far below the efficiency levels of modern buildings. The full goal and scope, methodology, results and conclusions of the study can be found in the subsequent sections of this report.

1.0 Introduction

The Neville Scarfe building is located in the centre of the University of British Columbia in Vancouver. The building was originally built to be a centre for teaching studies, as it remains today. In addition, the Scarfe building served as a location for teachers to congregate, much the same as a high school or elementary school teacher's lounge. Built in 1962, the funding for the Neville Scarfe building was received as a gift to UBC by the Department of Public Works. The building has subsequently undergone a series of upgrades and renovations; however, the original cost of the building was $1,103,877.

The gross area of the original version of the Scarfe building totaled 70,127 square feet, including classroom, lecture theaters, office and congregation space. Since its original design, a new library and two new classroom wings have been added. This report only focuses on those portions of the building contained in the original drawing specifications. To this day the building houses the University of British Columbia's school of teaching, as well as a number of student resource centers. The additions to the building have cost over $3,000,000 in addition to the original costs, with the last update being completed in 1995.

1.1 Lecture Theater

The lecture theater contained within the Scarfe building is the largest single activity space, totaling nearly 3000 square feet. The theater has a maximum capacity of 258 persons, and has a series of individual seats with a large theater stage. The entire step system of the lecture theater is concrete slab, with concrete cast-in-place walls. The exterior of the walls are covered in a tile mosaic for aesthetic effects. The theater is semi-detached and protrudes from the front face of the building. The main seating and stage portion of the theater are located underground, at the basement level; however the roof covering the entire area of the theater is one story above grade.

1.2 Basement

The basement of the Scarfe building is mostly excavated, with only one door leading outside. The basement includes space under the main classroom block of the building, but also part of the area underneath the lecture theater. The area underneath the lecture theater contains a large mechanical room, two electrical rooms and two storage rooms. Also contained in the area beneath the theater are two dressing rooms and bathrooms, accessible off to the side of the theater.

Under the classroom block, the basement contains six large storage rooms, two bathrooms and a large canteen area with an attached kitchen. All of these rooms are connected by a long corridor running the width of the basement. The bottoms of the two main stairwells in the building also begin in the basement, and are located at the north and south most points of the building, at either end of the main corridor. The entire floor of the basement is concrete slab-on-grade, while the walls are a combination of concrete cast-in-place and concrete block.

1.3 First Floor

The first floor in the building is the main floor and is dominated by a large entry way and atrium. The main floor area on the ground floor consists of one single open space, which is loosely broken up into two sections: the foyer and the student lounge. There are no walls separating these two areas. The main floor does have two separated rooms that are at the front face of the building. Also, the main entrance into the lecture theater is located in the foyer of the main floor, however all but the first few meters within the lecture theater are located beneath the main floor. As with the rest of the building, the main floor also contains two stairwells with respective portion of staircases.

All of the exterior walls of the main floor are concrete cast-in-place, while the interior walls are varying thicknesses of hollow clay tile walls. The hollow clay tile walls presented a challenge due to their rare nature, and are discussed in more detail later in this report. The floor of the first floor is a suspended slab system, which relies on a series of beams and columns extending from the foundations to support the various loads. The same columns used to support the ground floor continue through the floor and support subsequent floors as well.

1.4 Second Floor

The second floor of the building is located one floor above grade and has a slightly larger footprint than the main floor. Its floor is also a suspended concrete slab, supported by columns both inside and outside the main floor area. The front portion of the second floor exists as an overhanging section above the entry way to the main floor and is thus supported by exterior columns.

The second floor contains nine lecture rooms located along either side of a corridor similar to that of the basement. In addition, there are two smaller seminar rooms also along the same corridor. As with the ground floor, the partition walls on the second floor are all hollow clay tile walls. The entire exterior wall of the second floor is concrete cast-in-place, except at either stairwell, where knock-out walls were placed to allow for future renovations. Both the front and rear faces of the building contain a large number of windows, with enamel paneling in between. The windows are all operable and run the entire length of the front and back faces of the second floor.

1.5 Third Floor

The third and top floor of the building has an identical footprint area to the second floor below it. The majority of the third floor space is open and classified as a curriculum lab. There are a few closed off spaces on the third floor in addition to the curriculum lab, including: a bookstore, an office, four reading rooms and ten small study carrels. While all of the exterior walls are concrete cast-in-place, the interior walls are a combination of hollow clay tile and wood stud walls. As with the second floor, the third floor’s exterior faces are largely covered by windows and enamel paneling. Above the third floor there is a mechanical penthouse that sits in the center of the building’s roof. Because mechanical aspects of the building were not considered in this study, only the walls of the penthouse were taken into account.

The structure of the Scarfe building has a largely rectangular plan area, with a uniform appearance for both the front and rear faces. The only break in continuity of the building's exterior is the protruding lecture theater structure attached to the front face. Both the first and third floors have largely open floor plans, with few partition walls as dividers. The basement and second floor are separated into considerably smaller rooms of varying function. The basement in particular contains a number of side hallways and storage areas that make it unique from the rest of the building; however, the building's layout is generally quite common for a building of this era.

2.0 Goal of Study

This life cycle analysis (LCA) of the Neville Scarfe building at the University of British Columbia was carried out as an exploratory study to determine the environmental impact of its design. This LCA of the Scarfe building is also part of a series of twenty-nine others being carried out simultaneously on respective buildings at UBC with the same goal and scope.

The main outcomes of this LCA study are the establishment of a materials inventory and environmental impact references for the Scarfe building. An exemplary application of these references is for the assessment of potential future performance upgrades to the structure and envelope of the Scarfe building. When this study is considered in conjunction with the twenty-nine other UBC building LCA studies, further applications include the possibility of carrying out environmental performance comparisons across UBC buildings over time and between different materials, structural types and building functions. Furthermore, as demonstrated through these potential applications, this Scarfe building LCA can be seen as an essential part of the formation of a powerful tool to help inform the decision making process of policy makers in establishing quantified sustainable development guidelines for future UBC construction, renovation and demolition projects.

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

3.0 Scope of Study

The product systems being studied in this LCA are the structure and envelope of the Scarfe building on a square foot finished floor area of academic building basis. In order to focus on design related impacts, this LCA encompasses a cradle-to-gate scope that includes the raw material extraction, manufacturing of construction materials, and construction of the structure and envelope of the Scarfe building, as well as associated transportation effects throughout.

3.1 Tools

Two main software tools are to be utilized to complete this LCA study; OnCenter's OnScreen TakeOff and the Athena Sustainable Materials Institute's Impact Estimator (IE) for buildings.

The study will first undertake the initial stage of a materials quantity takeoff, which involves performing linear, area and count measurements of the building's structure and envelope. To accomplish this, OnScreen TakeOff version 3.6.2.25 is used, which is a software tool designed to perform material takeoffs with increased accuracy and speed in order to enhance the bidding capacity of its users. Using imported digital plans, the program simplifies the calculation and measurement of the takeoff process, while reducing the error associated with these two activities. The measurements generated are formatted into the inputs required for the IE building LCA software to complete the takeoff process. These formatted inputs as well as their associated assumptions can be viewed in Annexes A and B respectively.

Using the formatted takeoff data, version 4.0.64 of the IE software, the only available software capable of meeting the requirements of this study, is used to generate a whole building LCA model for the Scarfe building in the Vancouver region as an

Institutional building type. The IE software is designed to aid the building community in making more environmentally conscious material and design choices. The tool achieves this by applying a set of algorithms to the inputted takeoff data in order to complete the takeoff process and generate a bill of materials (BoM). This BoM then utilizes 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 focus on the manufacturing (inclusive of raw material extraction), transportation of construction materials to site and their installation as structure and envelope assemblies of the Scarfe building. As this study is a cradle-to-gate assessment, the expected service life of the Scarfe building is set to 1 year, which results in the maintenance, operating energy and end-of-life stages of the building's life cycle being left outside the scope of assessment.

3.2 Methodology

The IE then filters the LCA results through a set of characterization measures based on the mid-point impact assessment methodology developed by the US Environmental Protection Agency (US EPA), the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) version 2.2. In order to generate a complete environmental impact profile for the Scarfe building, all of the available TRACI impact assessment categories available in the IE are included in this study, and are listed as;

- Global warming potential
- Acidification potential
- Eutrophication potential
- Ozone depletion potential
- Photochemical smog potential
- Human health respiratory effects potential
- Weighted raw resource use
- Primary energy consumption

Using the summary measure results, a sensitivity analysis is then conducted in order to reveal the effect of material changes on the impact profile of the Scarfe building.

Finally, using the UBC Residential Environmental Assessment Program (REAP) as a guide, this study then estimates the embodied energy involved in upgrading the insulation and window R-values to REAP standards and generates a rough estimate of the energy payback period of investing in a better performing envelope.

3.3 Data

The primary sources of data used in modeling the structure and envelope of the Scarfe building are the original architectural and structural drawings from when the was initially constructed in 1961. The assemblies of the building that are modeled include the foundation, columns and beams, floors, walls and roofs, as well as their associated envelope and/or openings (ie. doors and windows). The decision to omit other building components, such as flooring, electrical aspects, HVAC system, finishing and detailing, etc., are associated with the limitations of available data and the IE software, as well as to minimize the uncertainty of the model. In the analysis of these assemblies, some of the drawings lack sufficient material details, which necessitate the usage of assumptions to complete the modeling of the building in the IE software. Furthermore, there are inherent assumptions made by the IE software in order to generate the bill of materials and limitations to what it can model, which necessitated further assumptions to be made. These assumptions and limitation will be discussed further as they emerge in the Building Model section of this report and, as previously mentioned, all specific input related assumption are contained in the Input Assumptions document in Annex B.

4.0 Building Model

4.1 Takeoffs

To begin assessing the environmental impacts of a building, the first requirement is to understand what it is made of. For the purposes of this study, this required a detailed account of all materials contained in the Neville Scarfe building. To complete the quantity takeoffs for these materials, OnCenter’s OnScreen Takeoff (OST) was used, as previously mentioned. A full license of OST was provided at the outset of the study, allowing for the utmost precision in the modeling of the building’s materials. In OST, the user has the ability to measure linear and area dimensions of objects opened in the program window. Since the drawing scale is provided, the program allows for precise measurement of individual assemblies within the building.

To simplify the recording of dimensions of various materials, the building was considered a sum of a number of individual assemblies. The building was split into: foundations, walls, columns, beams, floors, roofs and any extra materials encountered. By separating the building into these sub-categories, measurements of specific properties could be easily replicated for each assembly, and specific required information would be gathered. The only dimensions that were measured using OST were either linear or area values; however relevant information was also recorded based on descriptions on the drawings and site visits.

Since there were a number of different specified assembly types within each assembly group, it was prudent to follow a naming system that could identify each individual assembly. The naming format followed standard practices and followed the general outline of: assembly type_ assembly material_ specific member name_ assembly location_ relevant dimension. While simple, this naming format allows for quick indexing of the various assembly groups, and also provides the ability to quickly locate a specific assembly and reference its size. By including the assembly material in the name, later inputs into the Impact Estimator would be simplified. Within OST, each assembly was also modeled as a different colour. This created a visually obvious separation between various assemblies, in addition to the nomenclature followed.

While OnScreen Takeoff allows for the documenting of the building's attributes and dimensions, the source of all of this information is the building's drawings themselves. Both structural and architectural drawings were provided by the UBC Records Department, who are in possession of drawings for nearly all of the buildings on campus. These drawings were received as PDF images, which were then imported into OST. Although the drawings were quite comprehensive, the image quality was often quite low and a number of assumptions had to be made in regards to their interpretation. The drawings provided both the dimensions for assemblies, but also the materials used.

While OST did not require a material input, it was noted for all assemblies for later use in the Impact Estimator (as seen in Appendix A).

In total, 13 drawings were referenced for the quantity takeoffs of the Scarfe building. Many of these, including structural and architectural drawings for each floor, provided plan views that allowed for dimension measuring. Since all of the structural and architectural drawings had a scale of 1/8” = 1’, the modeling process was quite straightforward. In addition to the drawings used for actual takeoffs, a number of elevation view and detail section drawings were also used to extract height information of the building, and also to get a general sense for the building’s layout. For the most part, all properties of the various assemblies were given directly on the drawing. In cases where properties were not explicitly stated or the print was too difficult to read, assumptions were made based on the properties of similar assemblies in the building.

4.2 Modeling and Assumptions

The main challenge to completing the material takeoffs was the quality and information of the Scarfe building’s drawings. Since their creation in 1961, the drawings have obviously deteriorated, and the scanned versions tend to blur some of the drawings’ text. In addition, the drawings omit some key elements that are eventual inputs into the Impact Estimator. Both the concrete strength and flyash composition are missing from all of the drawings, again mainly because of the time period in which it was built. From previous Civil Engineering course work, it was estimated that at the time, concrete strength would be between 25MPa and 30Mpa, where the latter was used in the Impact Estimator. The flyash composition was most likely very minimal, if not non-existent; however, since the Impact Estimator requires an input for flyash composition, the “Average” value was used.

As previously stated, the building’s assemblies were broken into six different parts: foundations, walls, columns, beams, floors and roofs. Each of these assemblies had sub-categories for different materials, sizes and shapes, based on the drawing’s specifications. Since the Impact Estimator accepts only one value for most individual assembly inputs, it was necessary to create different sub-assemblies for elements with differing dimensions, even when elements shared all of the same properties. For simplicity, each assembly type was given its own layer in Onscreen Takeoff, and all elements were modeled per floor. While some elements such as columns and exterior walls may have been continuous for the entire height of the building, the modeling process was simplified by treating each floor as an isolated building.

4.2.1 Foundations

Foundations for a building can be either concrete footings, or concrete slab on grade, both of which exist in the Scarfe building. Concrete footings have a defined volume and therefore length, width and depth were all measured individually. Concrete slab on grade was measured only as a continuous area, where the thickness was listed on the drawings. The specifications for footings were given in much more detail than the slab on grade; with all rebar sizes and configurations explicitly stated. Both slab on grade and footings were modeled completely separately, but all concrete properties were assumed to be constant.

All stairs in the Scarfe building were also modeled as footings, with the dimensions being measured from both plan view and elevation view drawings. The length of the stairs was taken as the diagonal dimension from top to bottom of the staircase. The width of the stairs was measured from the plan view drawings and was simply the breadth of the entire stair case. Since this value was constant within each set of stairs, only one such measurement was required for entire set of stairs. The thickness of the stairs was taken as the depth from the walking surface to the underside of the stairs. The stairs were modeled as footings because this allowed for thickness and rebar inputs in the Impact Estimator, where slab on grade only has preset options for thickness and calculates the rebar accordingly.

4.2.2 Walls

The walls of the Scarfe building presented the most variety of any assembly. Within each floor, there were a number of different wall types, with each wall type also having varying thicknesses. There were four different wall types present in the building: concrete cast-in-place, concrete block, hollow clay tile and wood stud wall. All of the exterior walls of the building were concrete cast-in-place, with thicknesses varying from 10” to 15”. The interior partition walls included all four types, with the most common being the hollow clay tile. Walls were measured per linear foot, with all other values for material, thickness and height being recorded based on the drawing’s specifications. In instances where the wall properties were not explicitly stated on the drawings, thickness was measured and other properties were assumed based on similar elements.

4.2.3 Columns and Beams

Columns and beams were modeled separately in Onscreen Takeoff; however, they are ultimately interconnected in the modeling process. Both beams and columns were modeled very simply in the quantity takeoff, with only the length of the beams and the height of the columns being of importance. This is because the Impact Estimator automatically calculates the beam and column sizes depending on the floor slab and live load that they support. For reference, the sizes of the columns were recorded, so as to group them separately. Only the bay and supported span sizes of beams were recorded as this information was important when entering the assemblies into the Impact Estimator.

4.2.4 Floors and Roofs

Floors and roofs were also modeled quite similar to one another, with only envelope of the roof differing from the floor. Both floors and roofs were considered as suspended concrete slabs and were interconnected with the properties of the columns and beams on which they were supported. The supported span size of the columns and beams referred to the floor or roof that they were supporting. The thickness of the floor and roof were automatically calculated within the Impact Estimator software based on the loading and support conditions. In addition to the concrete for support, the roof of the building also had an envelope of various roofing materials. These materials were included for waterproofing and insulation purposes and were inputted into the Impact Estimator based on the closest known material.

4.2.5 Extra Basic materials

Building elements that could not be modeled exactly as they were described were simply measured for their areas, and considered to be equivalent to the closest substitute. For the Scarfe building, cladding materials constituted the majority of these materials. Many of these materials did not have an exact input within the Impact Estimator and a surrogate had to be used. The most substantial of these materials was: plaster from interior walls, insulation, enamel paneling and brick tiles.

Plaster was commonly used in older construction, but has subsequently been replaced by use of gypsum board. Since the plaster in the Scarfe building was specified as 5/8” plaster, a surrogate of 5/8” regular gypsum board was used. Similarly for insulation, no exact input was available for the rigid insulation specified in the drawing; however it was assumed that extruded polystyrene would most probably be an equivalent. Both insulation and gypsum board were considered as envelope materials, and were inputted directly as an envelope material for the wall it was on.

Enamel paneling on the building was located between the main windows on the front and rear faces. Since no direct surrogate exists within the Impact Estimator the standard glazing material was used instead. The total area of the enamel panels was measured and included as this standard glazing material within the extra basic materials. Brick and clay tiles were abundant in the Scarfe building, being used for everything from interior walls to exterior cladding. While the brick cladding on walls could be modeled as an envelope material, it most often did not cover an entire wall. Since Impact Estimator does not allow for partial covering of a wall by a material, the surface area was instead included as modular brick in extra basic materials. In addition, a number of interior walls were included as hollow clay tile walls, which also does not have a direct input within Impact Estimator. For simplicity, these walls were also considered to be modular brick walls and grouped together with the aforementioned bricks.

4.3 Unknown Inputs

As there were often disconnects between the inputs in the Onscreen Takeoff software and the Impact Estimator, many inputs had to be adjusted or filled in prior to being entered into the Impact Estimator. For many assembly types, the Impact Estimator only allows a choice between two or three preset dimensions, which were often not the exact values obtained for the building. In such cases, these dimensions were constrained, but other dimensions were adjusted such that the total unit of the assembly would remain constant. All of the measured values and the subsequent Impact Estimator inputs can be found within the IE Input document in Annex A while details of all assumptions made can be found in the IE Assumptions document in Annex B. The assumptions page shows sample calculations as to why and how these elements were adjusted to fit into the Impact Estimator framework.

5.0 Bill Of materials

Once all of the assemblies were entered into the Impact Estimator, the first output was a list of all of the materials embodied within the building. This Bill of Materials shows many materials that are specifically input into the software, such as gypsum board and glazing panel. Also shown on the bill are materials that are embodied within other assemblies such as the roof and concrete walls. The bill for the Scarfe building is shown in table 1, and contains the amount of each building materials used, including the amount wasted during construction. The bill of materials helps to demystify the Impact Estimator, since during the input stages; the detail of materials is on a much more general level.

Table 1. Bill of Materials for the Neville Scarfe building

Material	Quantity	Unit
#15 Organic Felt	3076.7451	m2
5/8" Regular Gypsum Board	1207.9108	m2
6 mil Polyethylene	4347.6248	m2
Aluminum	0.7606	Tonnes
Ballast (aggregate stone)	28337.7498	kg
Batt. Fiberglass	21.8802	m2 (25mm)
Blown Cellulose	2835.9286	m2 (25mm)
Concrete 30 MPa (flyash av)	2813.0416	m3
Concrete Blocks	2309.9466	Blocks
EPDM membrane	407.8044	kg
Expanded Polystyrene	15.96	m2 (25mm)

Extruded Polystyrene	2420.7839	m2 (25mm)
Galvanized Sheet	1.9836	Tonnes
Glazing Panel	0.192	Tonnes
Joint Compound	1.2055	Tonnes
Metric Modular (Modular) Brick	2091.3358	m2
Mortar	484.8619	m3
Nails	1.4265	Tonnes
Paper Tape	0.0138	Tonnes
Rebar, Rod, Light Sections	148.4093	Tonnes
Roofing Asphalt	18156.8441	kg
Small Dimension Softwood Lumber, Green	2.587	m3
Small Dimension Softwood Lumber, kiln-dried	17.5367	m3
Softwood Plywood	256.8861	m2 (9mm)
Solvent Based Alkyd Paint	1.4487	L
Standard Glazing	324.5651	m2
Type III Glass Felt	6153.4901	m2
Water Based Latex Paint	108.3923	L
Welded Wire Mesh / Ladder Wire	1.8108	Tonnes

Since the Scarfe building has a more open layout, the most substantial material contributions arise from the roof structure. The three largest areas are all materials used for roofing (Glass Felt, Polyethylene, Organic Felt) while the largest material by weight and volume were steel rebar and concrete respectively. While the dominance of the roofing materials may be expected due to the large nature of the roof structure, it must also be noted that the envelope from which these materials arise was assumed to be similar to what is actually in place. No specific type of roof was listed for the Scarfe building; however the materials shown are all present in the type of cladding that was used. While it is highly likely that the roofing materials would dominate the total bill of materials regardless of the input, it is worth noting that the inputs were made based on assumptions.

The fact that concrete and rebar are also among the most substantial materials used is of course no surprise, considering that nearly all of the building’s walls and foundation are reinforced concrete. The rebar value, however, may also be slightly inflated due to the minimal rebar choice options in the Impact Estimator. Many of the walls in the Neville Scarfe building specified #4 steel reinforcing bars, while some footings were specified as plain concrete, with no rebar. Since the Impact Estimator requires an input for rebar of #5 or #6 for walls, and of #4, #5 or #6 for footings, there were a number of cases where excess rebar was specified. While this may not drastically alter the total amount of rebar contained in the building, the actual weight would be slightly lower.

6.0 Summary Measures

Once all of the building material inputs had been entered into the Impact Estimator, a report was generated that defines the potential for a number of different environmental impacts. These impacts are further categorized based on the period within the life cycle at which they occur. In this case, only the manufacturing and construction phases were considered, as operating and decommissioning were outside the scope of this study. Table 2 shows the total potential for various environmental effects for both the construction and manufacturing stages of the life cycle. Table 2 also shows the total amount of these impacts over both phases, as well as per square foot of building space. The impacts per square foot are useful when comparing the building to other similar buildings.

Table 2. Impact potential for manufacturing and construction stages

Summary Measures	Manufacturing			Construction		
	Material	Transportation	Total	Material	Transportation	Total
Primary Energy Consumption MJ	11527221	331696.0943	11858917	581594.2	1063109.421	1644704
Weighted Resource Use kg	8876202.1	220.6805831	8876423	13480.289	647.4009337	14127.69
Global Warming Potential (kg CO2 eq)	1191962.2	584.784022	1192547	39385.713	1785.105622	41170.82
Acidification Potential (moles of H+ eq)	493760.82	199.9236516	493960.7	20465.264	576.0544555	21041.32
HH Respiratory Effects Potential (kg PM2.5 eq)	3318.2121	0.241057457	3318.453	22.97633	0.692960802	23.66929
Eutrophication Potential (kg N eq)	442.7457	0.208171692	442.9539	20.272486	0.597647801	20.87013
Ozone Depletion Potential (kg CFC-11 eq)	0.0023405	2.40963E-08	0.002341	1.544E-12	7.31359E-08	7.31E-08
Smog Potential (kg NOx eq)	5857.2526	4.509023942	5861.762	501.08096	12.88777242	513.9687

Summary Measures	**Total Effects**	**Total Effects**
		(Per Sq. Foot)
Primary Energy Consumption MJ	**13503621.11**	**196.0295917**
Weighted Resource Use kg	**8890550.5**	**126.7804471**
Global Warming Potential (kg CO2 eq)	**1233717.774**	**17.59994674**
Acidification Potential (moles of H+ eq)	**515002.0591**	**7.345988511**
HH Respiratory Effects Potential (kg PM2.5 eq)	**3342.12241**	**0.047660703**
Eutrophication Potential (kg N eq)	**463.824009**	**0.00661607**
Ozone Depletion Potential (kg CFC-11 eq)	**0.002340645**	**3.33775E-08**
Smog Potential (kg NOx eq)	**6375.730316**	**0.090964334**

The eight summary measures that are reported by the Impact Estimator are the main focus of this entire study and are listed in table 2. These values provide an absolute gauge as to the environmental impacts that resulted from the development of the Neville Scarfe Building. The primary energy consumption, measured in Mega Joules, is the total embodied energy that went into creating this building. This value can be used to track the cost of energy consumption for the building's construction, but in a region other than British Columbia, could also be converted to a volume of fossil fuel consumption. The weighted resource use simply provides a total for the weight of the materials that went into the building's construction. This value can be broken up into individual assemblies to see where the most weight is occurring.

6.1 Summary Measure Details

The global warming potential of the building stems from the production, transportation and installation of all the materials used. While this is made up of a number of different chemical compounds, the value is reported in CO_2 equivalents. By standardizing the reporting method for these values it allows for more simplified reporting and comparison. Similarly, the acidification, respiratory effects, ozone depletion and smog potential have been normalized to the specific compound referenced in table 2. While further research shows that again there are a number of other harmful compounds that combine to create this potential, the easiest method of reporting is to refer to a reference compound that is released to the air. Finally, the Eutrophication potential refers to the potential of the emissions to cause a water body to become overly nutrient rich and begin a slide towards of oxygen depletion. This value has also been shown in Nitrogen equivalents, as this is the most common source of eutrophication potential.

6.2 Summary Measure Assumptions

While the summary measures do provide a reasonable evaluation of the Scarfe building's environmental impact, it is important to keep in mind that there is some uncertainty engrained in these results. Aside from any mistakes or assumptions that may have arisen from the modeling of the building, the results are heavily dependant on the Athena LCI database. While many studies have been conducted, and there are large amounts of materials included in the LCI database, there is the strong possibility that the materials sourced for this project have different impacts. As technology and efficiency improve, so to do manufacturing processes, meaning the production and transportation costs reported for a materials life cycle assessment may already be outdated. In addition, because Vancouver is a relatively large city, the transportation costs could be different from what is estimated. With UBC being quite secluded from much of Vancouver, and most manufacturing plants, it is quite possible that these impacts would be much higher. While it is very difficult to ever have a truly accurate building life cycle assessment, the environmental impacts should always be viewed with the realization that there is an inherent inaccuracy built in.

7.0 Sensitivity Analysis

A sensitivity analysis was then performed for the summary measures of the Scarfe building, to see which materials had the most potential influence. Out of the bill of materials, five of the materials with the highest usage were chosen to analyze their impact on the overall building. The five materials chosen were: Concrete (30Mpa), Type III glass felt, Steel Rebar, Roofing Asphalt and Gypsum. These materials were chosen because of the quantities used in the Scarfe building, but also because they were some of the more commonly known building materials. The sensitivity of the building to each material was tested by adding 10% of the material to the original building, and comparing the results. This was completed for each of the five aforementioned materials, and the results are presented in table 3, and graphically in figure 1.

Table 3. Percent change in summary measures for 10% increase in materials

Material	**Concrete**	**Glass Felt**	**Rebar**	**Asphalt**	**Gypsum**
Measure	Percent Change (for 10% material increase)				
Primary Energy Consumption	3.761%	0.068%	2.108%	1.350%	0.093%
Weighted Resource Use	8.332%	0.006%	0.269%	0.047%	0.030%
Global Warming Potential	6.322%	0.015%	0.774%	0.647%	0.056%
Acidification Potential	6.032%	0.020%	0.623%	0.778%	0.074%
HH Respiratory Effects Potential	6.419%	0.017%	0.538%	0.598%	0.094%
Eutrophication Potential	4.072%	0.004%	4.003%	0.284%	0.016%
Ozone Depletion Potential	6.829%	0.000%	0.003%	0.017%	0.001%
Smog Potential	6.562%	0.019%	0.125%	0.558%	0.019%
Average	**6.041%**	**0.019%**	**1.055%**	**0.535%**	**0.048%**

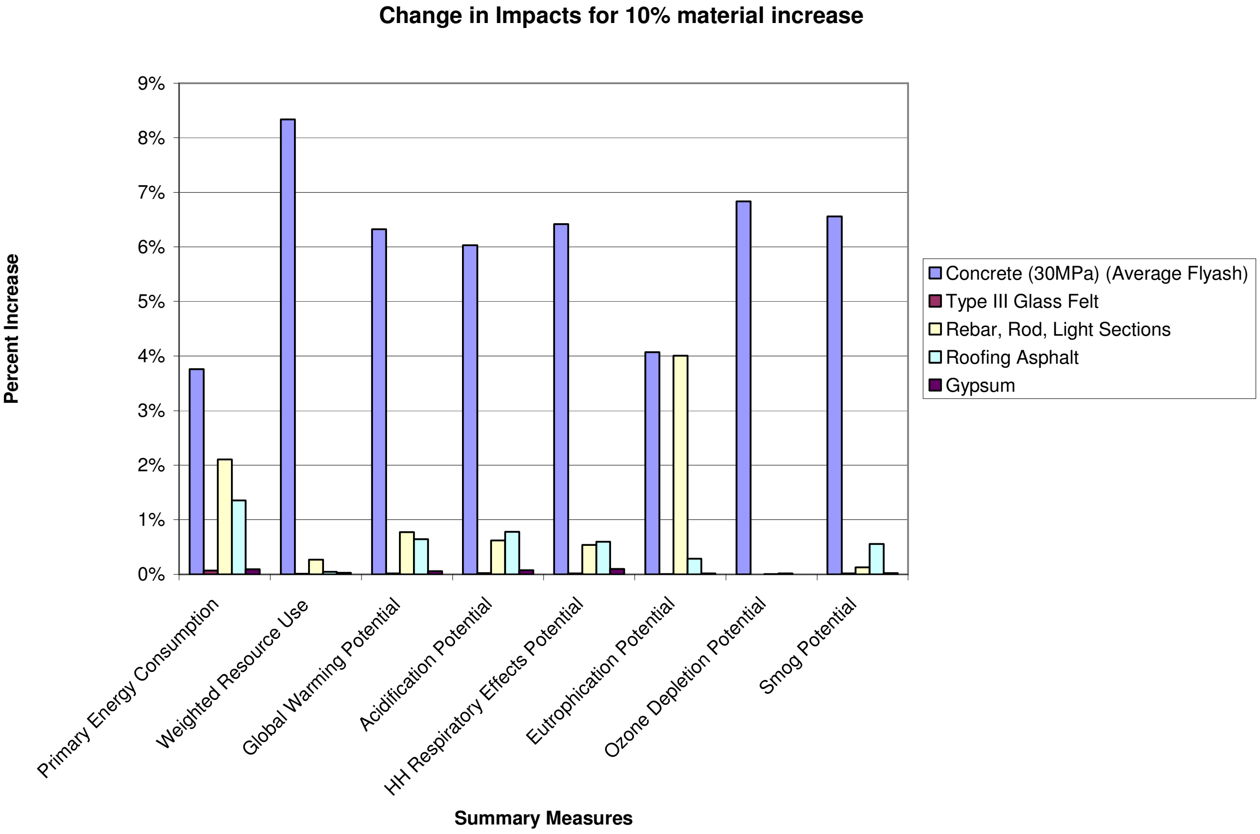

Figure 1. Graphical representation of summary measure increase for 10% material increase

As is shown in table 3, the average influence of each of the materials varies from an increase of 6.04% for concrete, to .019% for glass felt. The sensitivity of the building to each building material is important since it can be used in decision making for future building projects. While use of many building materials is unavoidable, developers and contractors would be able to see which materials create the most harmful emissions, and make material selections based on this, for a specific region. By creating a source of reference for buildings similar to the Scarfe building at UBC, this could be further exploited specifically for academic buildings on campus. This would also be highly applicable to renovations of the Scarfe building, since one could see minimizing the use of certain materials, such as concrete, would be beneficial.

8.0 Building Performance

As with most buildings built before the 1990s, the Neville Scarfe building's material usage does not favor energy conservation. Specifically, the windows of the building, which are still in place, are wood framed, single pane windows. When standing beside these windows, one can feel a noticeable draft, one very obvious sign that there is significant heat being lost through the windows. Also, the use of insulation is quite minimal throughout the building, with many areas being un-insulated. Both the drafty windows and lack of insulation mean that during colder months, heat is being lost through the exterior walls of the building. This results in an increase in indoor heating demand, which subsequently increases the amount of electricity used.

8.1 Existing Building

To evaluate the building performance for the Scarfe building, the building's total embodied energy was calculated for the building's original design. The embodied energy value was a combination of the primary energy consumption resulting from the manufacturing and construction of the building materials, and the total energy loss projected for the life of the building. The energy loss of the building was calculated by first obtaining the average temperature data for the surrounding area and comparing it to a constant room temperature of 20 degrees Celsius. The insulation used in the walls and roof, as well as the current windows were then assigned a specific coefficient of heat transfer. This value is a measure of how well a specific material is insulated. The total amount of heat flow through these surfaces was then calculated using the following equation:

$$Q = \frac{1}{R} * A_{Surface} * \Delta T$$

Where: Q = total heat flow

R= thermal conductivity coefficient

A= Total exposed surface area

DT=Temperature difference between outside and inside

The resulting value is then multiplied by the number of hours in each month, and then converted to Joules.

8.2 Improved Building

To theoretically improve the building, it was proposed that the R value for wall insulation be increased from 5 to 18 and the R value for roof insulation be increased from 5 to 40. To model this, the total exterior wall area of the Scarfe building was measured, and a ratio of 13/5 of extra extruded polystyrene insulation was added in the extra basic materials. Furthermore, within the envelope dialog box, seven extra inches of the same insulation were added. Since the R values were specified per inch of insulation, it was assumed that the insulation would be distributed evenly along the walls and roof, and could therefore be included as described above. The windows in the building were also upgraded in the improved building model, with the wood frame single pane windows being replaced by aluminum framed Low E Silver Argon filled windows.

While improving the building materials does increase the initial primary energy consumption, the payback period for the Scarfe building is extremely fast. As can be seen in figure 2, the payback period in energy savings for the theoretical upgrades is just under two years. This comparison shows that while there will definitely be more energy spent in the manufacturing and installation of these extra insulating materials, the energy savings they provide will equal their entire primary energy consumption in less than two years. While this is a highly simplified calculation for a building’s performance, it provides an eye-opening view at the inefficiency of older buildings, and how simply they can be improved. Although the payback period for the monetary investment would undoubtedly be longer than the energy savings, as heating costs continue to rise, this payback period will also continue to get smaller.

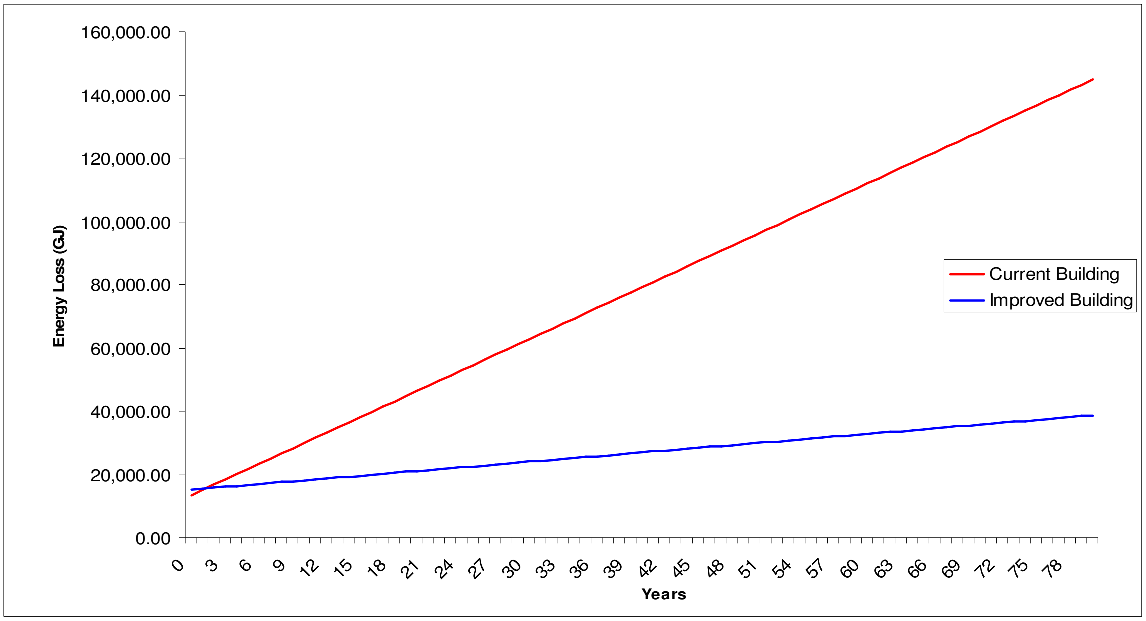

Figure 2. Energy savings (blue line) for improved building insulation

9.0 Conclusions

The life cycle assessment for the Neville Scarfe building highlighted some key problems with buildings from the early to mid 20th century. The Scarfe building first presented a challenge to model, as many of the inputs required by the Impact Estimator were simply not included. While assumptions were made to include these elements using a similar surrogate, this proved to be a main source of uncertainty in the assessment process. Once the building was modeled, the impacts of all of the building materials were calculated, and were within the range of most other academic buildings at UBC. As the main building material employed was concrete, a sensitivity analysis showed that it had the most significant influence on the overall environmental impact of the building. A test to increase the concrete volume by 10% resulted in an average of 6% increase over the eight summary measures. When modeling the energy performance of the building, the inefficiencies of the Scarfe building were clearly displayed. It was shown that adding roughly five times the current amount of insulation would drastically reduce the amount of energy loss in the building. The energy savings were shown to equal the total embodied energy of the extra material in under two years, proving this would be an extremely enticing option for renovation.

After completing the LCA for this segment of the Scarfe building, the next step would be to model the subsequent additions to the building. These additions would be of interest for two reasons: to further compile LCA’s for UBC academic buildings, and to compare the costs of the original building to its updates. As the most recent update to the building was in 1995, a comparison between the type and amount of materials from 1961 to 1995 would provide an interesting view of the changing methods of the construction industry. As UBC is continuously updating its facilities, this LCA can serve as a benchmark for the Neville Scarfe building. Whether a new renovation is planned, or an entire new facility, the values determined in this study are a reference point for what impacts can be expected, and possible alternatives that can be used to minimize them.

Annex A

IE Input Document

Assembly Group	Assembly Type	Assembly Name	Input Fields	Input Values	
				Known/ Measured	IE Inputs
1 Foundation					
	1.1 Concrete Slab-on-Grade				
		1.1.1 SOG_BSMNT_6"			
			Length (ft)	81.22	99.48
			Width (ft)	81.22	99.48
			Thickness (in)	6	4
			Concrete (psi)	-	3000
			Concrete flyash %	-	average
		Envelope	Category	Coating	Envelope
			Material	Vapour Barrier	Vapour Barrier
			Thickness		6 mil
		1.1.2 SOG_Tunnel_6"			
			Length (ft)	87.97	107.74
			Width (ft)	87.97	107.74
			Thickness (in)	6	4
			Concrete (psi)	-	3000
			Concrete flyash %	-	average
		Envelope	Category	Coating	Envelope
			Material	Vapour Barrier	Vapour Barrier
			Thickness		6 mil
	1.2 Concrete Footing				
		1.2.1 FTG_F1			
			Length (ft)	4.75	5.90197707
			Width (ft)	5.5	5.90
			Thickness (in)	24	18.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#5	#5
			Quantity	7	
		1.2.2 FTG_F2			
			Length (ft)	2.5	2.5
			Width (ft)	2.5	2.50
			Thickness (in)	18	18.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	None	#4

			Quantity	7	
		1.2.3. FTG_F3			
			Length (ft)	2.583333333	2.583333333
			Width (ft)	2.583333333	2.58
			Thickness (in)	18	18.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	none	#4
			Quantity	5	
		1.2.4 FTG_F4			
			Length (ft)	4.25	5.322906474
			Width (ft)	5	5.32
			Thickness (in)	24	18.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#5	#5
			Quantity	4	
		1.2.5 FTG_F5			
			Length (ft)	4.5	6
			Width (ft)	6	6.00
			Thickness (in)	24	18.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4 & #5	#4
			Quantity	3	
		1.2.6 FTG_F6			
			Length (ft)	3.5	3.741657387
			Width (ft)	4	3.74
			Thickness (in)	18	18.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4	#4
			Quantity	1	
		1.2.7 FTG_F7			
			Length (ft)	4.333333333	5.374838499
			Width (ft)	5	5.37
			Thickness (in)	24	18.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4	#4
			Quantity	1	
		1.2.8 FTG_F8			
			Length (ft)	5.75	6.639528096
			Width (ft)	5.75	6.64
			Thickness (in)	24	18.00
			Concrete (psi)	-	4000

	Concrete flyash %	-	average
	Rebar	#5	#5
	Quantity	5	
1.2.9 FTG_F9			
	Length (ft)	6.333333333	7.31310341
	Width (ft)	6.333333333	7.31
	Thickness (in)	24	18.00
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	#6	#6
	Quantity	8	
1.2.10 FTG_F10			
	Length (ft)	6.333333333	7.31310341
	Width (ft)	6.333333333	7.31
	Thickness (in)	24	18.00
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	#5	#5
	Quantity	1	
1.2.11 FTG_F11			
	Length (ft)	2.5	4.082482905
	Width (ft)	5	4.08
	Thickness (in)	24	18.00
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	#4	#4
	Quantity	2	
1.2.12 FTG_F12			
	Length (ft)	2.583333333	2.982976391
	Width (ft)	2.583333333	2.98
	Thickness (in)	24	18.00
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	None	#4
	Quantity	5	
1.2.13 FTG_F13			
	Length (ft)	5.00	6.32455532
	Width (ft)	6.00	6.32
	Thickness (in)	24.00	18.00
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	#5 & #6	#5
	Quantity	1	
1.2.14 Footing_Strip_Bsmnt_ 16"			

			Length (ft)	0.00	0
			Width (ft)	0.00	0.00
			Thickness (in)	27.56	0.00
			Concrete (psi)	4000	4000
			Concrete flyash %	-	average
			Rebar	#7	#7
		1.2.15 Stairs_Concrete_North_Stairwell			
			Length (ft)	66	66
			Width (ft)	10	10.00
			Thickness (in)	9.5	10.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.15 Stairs_Concrete_South_Stairwell			
			Length (ft)	70	70
			Width (ft)	5.125	5.13
			Thickness (in)	12	12.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.15 Stairs_Concrete_Tunnel_Access			
			Length (ft)	7	7
			Width (ft)	3	3.00
			Thickness (in)	10	10.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.15 Stairs_Concrete_Lecture-Theater			
			Length (ft)	36	36
			Width (ft)	53	53.00
			Thickness (in)	16	16.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	-	#4
		1.2.15 Stairs_Concrete_BSMNT_Access			
			Length (ft)	43	43
			Width (ft)	4.833333333	4.83
			Thickness (in)	16	16.00
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4,#5 &#6	#5
2 Walls					
	2.1 Cast In Place				
		2.1.1 Wall_Cast-in-			

Place_W9_BSMNT_12"			
	Length (ft)	667	667.00
	Height (ft)	10.5	10.5
	Thickness (in)	12	12
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	#4	#5
Envelope	Category	Insulation	Insulation
	Material	Rigid Insulation	Polystyrene Extruded
	Thickness	1"	1"
Envelope	Category	Wall Cover	Gypsum Board
	Material	Plaster	Regular Gypsum 5/8"
	Thickness	5/8"	5/8"
Envelope	Category	Wall Cover	Vapour Barrier
	Material	Waterproof Membrane	Polyethylene 6 mil
	Thickness	-	-
Door Opening	Number of Doors	8	8
	Door Type	-	Steel Exterior w/ glazing
2.1.2 Wall_Cast-in-Place_W8_BSMNT_10"			
	Length (ft)	118	98.33333333
	Height (ft)	10.5	10.5
	Thickness (in)	10	12
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	#5	#5
Envelope	Category	Insulation	Insulation
	Material	Rigid Insulation	Polystyrene Extruded
	Thickness	1"	1"
Envelope	Category	Wall Cover	Gypsum Board
	Material	Plaster	Regular Gypsum 5/8"
	Thickness	5/8"	5/8"
2.1.3 Wall_Cast-In-Place_W10_BSMNT_15"			
	Length (ft)	89	111.25
	Height (ft)	10.5	10.5
	Thickness (in)	15	12
	Concrete (psi)	-	4000
	Concrete flyash %	-	average
	Rebar	#5	#5
Envelope	Category	Insulation	Insulation
	Material	Rigid Insulation	Polystyrene Extruded

			Thickness	1"	1"
		Envelope	Category	Wall Cover	Gypsum Board
			Material	Plaster	Regular Gypsum 5/8"
			Thickness	5/8"	5/8"
		Envelope	Category	Wall Cover	Vapour Barrier
			Material	Waterproof Membrane	Polyethylene 6 mil
			Thickness	-	-
		2.1.4 Wall_Cast-In-Place_W12_BSMNT_6"			
			Length (ft)	156	117
			Height (ft)	11	11
			Thickness (in)	6	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#5	#5
		Envelope	Category	Insulation	Insulation
			Material	Rigid Insulation	Polystyrene Extruded
			Thickness	1"	1"
		Envelope	Category	Wall Cover	Gypsum Board
			Material	Plaster	Regular Gypsum 5/8"
			Thickness	5/8"	5/8"
		Door Opening	Number of Doors	3	3
			Door Type	-	Standard 32x7 solid core
		2.1.5 Wall_Cast-in-Place_W11_BSMNT_4"			
			Length (ft)	43	21.5
			Height (ft)	10.50	10.5
			Thickness (in)	4	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#5	#5
		Envelope	Category	Insulation	Insulation
			Material	Rigid Insulation	Polystyrene Extruded
			Thickness	1"	1"
		Envelope	Category	Wall Cover	Gypsum Board
			Material	Plaster	Regular Gypsum 5/8"
			Thickness	5/8"	5/8"
		2.1.6 Wall_Cast-in-Place_W16_GRND_10"			
			Length (ft)	566	471.6666667

			Height (ft)	10.5	10.5
			Thickness (in)	10	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category	Cladding	added in XBM
			Material	Tile Mosaic Wall	
			Thickness		
		Door Opening	Number of Doors	17	17
			Door Type	-	Standard 32x7 solid core
		2.1.7 Wall_Cast-in-Place_W18_GRND_12"			
			Length (ft)	165	165
			Height (ft)	10.5	10.5
			Thickness (in)	12	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar		#5
		Door Opening	Number of Doors	8	8
			Door Type	-	Standard 32x7 solid core
		Window Opening	Number of Windows	25	25
			Window Frame Type	-	Wood Frame
			Total Window Area	1286	1286
		2.1.7 Wall_Cast-in-Place_W18_GRND_12"			
			Length (ft)	659	659
			Height (ft)	11.41666667	11.41666667
			Thickness (in)	12	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar		#5
		Door Opening	Number of Doors	6	6
			Door Type	-	Standard 32x7 solid core
		Window Opening	Number of Windows	56	56
			Window Frame Type	-	Wood Frame
			Total Window Area	1918	1918
		2.1.9 Wall_Cast-in-Place_W4_3rd_12"			

			Length (ft)	644	644
			Height (ft)	11.41666667	11.41666667
			Thickness (in)	12	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar		#5
		Envelope	Category Material Thickness		
		Door Opening	Number of Doors	5	5
			Door Type	-	Standard 32x7 solid core
		Window Opening	Number of Windows	56	56
			Window Frame Type	-	Wood Frame
			Total Window Area	1948	1948
		2.1.10 Wall_Cast-in-Place_W20_Tunnel_15"			
			Length (ft)	176	220
			Height (ft)	8	8
			Thickness (in)	15	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category Material Thickness		
		2.1.11 Wall_Cast-in-Place_W21_Tunnel_12"			
			Length (ft)	654	654
			Height (ft)	8	8
			Thickness (in)	12	12
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category Material Thickness		
		2.1.12 Wall_Cast-in-Place_W22_Tunnel_8"			
			Length (ft)	239	239
			Height (ft)	8	8
			Thickness (in)	8	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average

			Rebar	#4	#5
		Envelope	Category Material Thickness		
		2.1.13 Wall_Cast-in-Place_W23_Tunnel_6"			
			Length (ft)	152	114
			Height (ft)	8	8
			Thickness (in)	6	8
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Rebar	#4	#5
		Envelope	Category Material Thickness		
	2.2 Concrete Block Wall				
		2.2.1 Wall_ConcreteBlock_W15_BSMNT_8"			
		8	Length (ft)	98	98
			Height (ft)	7	7
			Rebar	#5	#5
		Envelope	Category	Wall Cover	Gypsum Board
			Material	Plaster	Regular Gypsum 5/8"
			Thickness	5/8"	-
		2.2.2 Wall_ConcreteBlock_W14_BSMNT_6"			
		6	Length (ft)	80	60
			Height (ft)	11	11
			Rebar	#5	#5
		Envelope	Category	Wall Cover	Gypsum Board
			Material	Plaster	Regular Gypsum 5/8"
			Thickness	5/8"	-
		Door Opening	Number of Doors	2	2
			Door Type	-	Standard 32x7 solid core
		2.2.3 Wall_ConcreteBlock_W13_BSMNT_4"			
		4	Length (ft)	68.4	34.2
			Height (ft)	12	12
			Rebar	#4	#4
		Door Opening	Number of Doors	34	34

			Door Type	-	Standard 32x7 solid core
		2.2.4 Wall_ConcreteBlock_W3_2nd_8"			
		8	Length (ft)	15	15
			Height (ft)	10'5"	12
			Rebar	#4	#4
		Door Opening	Number of Doors		
			Door Type		
		2.2.5 Wall_ConcreteBlock_W6_3rd_6"			
		6	Length (ft)	31	23.25
			Height (ft)	11'5"	12
			Rebar	#4	#4
		Door Opening	Number of Doors		
			Door Type		
	2.3 Hollow Clay Tile				
		2.3.1 Wall_Hollow_Clay_Tile_W28_GRND_6"			
		6	Length (ft)	121.5	981.5
			Height (ft)	9	Input sq. ft into XBM
		Envelope	Category	Wall Cover	Gypsum Board
			Material	Plaster	Regular Gypsum 5/8"
			Thickness	5/8"	-
		Door Opening	Number of Doors	6	6
			Door Type	-	Standard 32x7 solid core
		2.3.2 Wall_Hollow_Clay_Tile_W17_GRND_4"			
			Length (ft)	216	1869.333333
			Height (ft)	9	Input sq. ft into XBM
		Door Opening	Number of Doors	4	4
			Door Type	-	Standard 32x7 solid core
		2.3.3 Wall_Hollow_Clay_Tile_W2_2nd_4"			
			Length (ft)	698	7558.166667
			Height (ft)	11.41666667	Input sq. ft into XBM
		Door Opening	Number of Doors	22	22
			Door Type	-	Standard 32x7 solid

					core
		2.3.4 Wall_Hollow_Clay_Tile_W5_3rd_4"			
		Door Opening	Length (ft)	415	4607.25
			Height (ft)	11.41666667	Input sq. ft into XBM
			Number of Doors	7	7
			Door Type	-	Standard 32x7 solid core
	2.4 Wood Stud				
		2.4.1 Wall_Wood_Stud_W7_3rd_2x4"			
		Door Opening	Length (ft)	208	197.8888889
			Height (ft)	11.41666667	12
			Number of Doors	15	15
			Door Type	-	Standard 32x7 solid core
3 Columns and Beams					
	3.1 Concrete Column				
		3.1.1 Column_Concrete_Beam_N/A_BSMNT			
			Number of Beams	0	0
			Number of Columns	40	40
			Floor to floor height (ft)	10	10
			Bay sizes (ft)		12.84
			Supported span (ft)		12.84
			Live load (psf)	-	75
		3.1.2 Column_Concrete_Beam_Concrete_GRND			
			Number of Beams	9	9
			Number of Columns	32	32
			Floor to floor height (ft)	10'5"	10'5"
			Bay sizes (ft)	27.5	27.5
			Supported span (ft)	20	20
			Live load (psf)	-	75
		3.1.3 Column_Concrete_Beam_Concrete_2nd			
			Number of Beams	9	9
			Number of Columns	44	44

			Floor to floor height (ft)	10'5"	10'5"
			Bay sizes (ft)	26.7	26.7
			Supported span (ft)	20	20
			Live load (psf)	-	75
		3.1.4 Column_Concrete_Beam_Concrete_3rd			
			Number of Beams	9	9
			Number of Columns	38	38
			Floor to floor height (ft)	10'5"	10'5"
			Bay sizes (ft)	26.7	26.7
			Supported span (ft)	20	20
			Live load (psf)	-	75
4 Floors					
	4.1 Concrete Suspended Slab				
		4.1.1 Floor_Suspended_Slab_GRND_6"			
			Floor Width (ft)	620.20	620.20
			Span (ft)	20.00	20
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Live load (psf)	-	75
		4.1.2 Floor_Suspended_Slab_2nd_6"			
			Floor Width (ft)	675.25	675.25
			Span (ft)	20.00	20
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Live load (psf)	-	75
		4.1.3 Floor_Suspended_Slab_3rd_6"			
			Floor Width (ft)	680.15	680.15
			Span (ft)	20.00	20
			Concrete (psi)	-	4000
			Concrete flyash %	-	average
			Live load (psf)	-	75
5 Roof					
	5.1 Concrete Suspended Slab				
		5.1.1 Roof_ConcreteSuspendedSlab_6"			
			Roof Width (ft)	726.25	726.25
			Span (ft)	20.00	20
			Concrete (psi)	-	4000
			Concrete flyash %	-	average

			Live load (psf)	-	75
		Envelope	Category	Roof Envelopes	Roof Envelopes
			Material	-	Built Up asphalt
			Thickness	-	4
			Category	Vapour Barrier	Vapour Barrier
			Material	-	Polyethylene 6 mil
			Thickness	-	-
		Envelope	Category	Gypsum	Gypsum Board Regular
			Material	-	Gypsum 5/8"
			Thickness	-	
			Category	Insulation	Insulation
			Material	-	Polystyrene Extruded
			Thickness	-	1
6 Extra Basic Materials					
	6.1 Enamel				
		6.1.1 XBM_Cladding_Enamel		Area	
			Enamel_Face_Cladding	3459	3,459.00
	6.2 Brick				
		6.1.2 XBM_Cladding_Glazed Brick		Area	
			Brick_Face_Cladding	3329	3,329.00
	6.3 Tile		Mortar	98.54	98.54
		6.1.3 XBM_Cladding_Mosaic Tile		Area	
			Mosaic_Face_Cladding	3095	3,095.00

Annex B

IE Assumptions Document

Assembly Group	Assembly Type	Assembly Name	Specific Assumptions
1 Foundations	-The Impact Estimator, SOG inputs are limited to being either a 4” or 8” thickness. All SOG in the Neville Scarfe Building were 6" thick, meaning that this would have to be adjusted to either of the other two thicknesses. In all cases, a nominal thickness of 4" was assumed, and the width and length dimensions of the slab were adjusted accordingly. -The Impact Estimator limits the thickness of footings to be between 7.5” and 19.7” thick. Many of the footings in the Neville Scarfe building are 24" Thick, and had to be adjusted to fit within the IE constraints. Since a number of the footings had a depth of 18", it was decided to standardize the size of the footings to a uniform depth of 18" and adjust the width and length inputs accordingly. -Since there were often a number of the same type of footing, the number of each footings was simply inputted into IE as a copy of the master footing. -The concrete stairs were also modelled as footings. Each set of stairs were modelled differently since they all had different widths and thicknesses. The Lecture theater was also treated as a set of stairs, since it has all the same materials and shape properties. -The Vapour barrier for both SOG was assumed to be 6mil		
	1.1 Concrete Slab-on-Grade		
		1.1.1 SOG_BSMNT_6"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator (Where the actual thickness is 6"). The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt(Total Sq. feet*(6"/4")) = sqrt[(6597 x (1.5)] = 99.48 feet

		1.1.2 SOG_Tunnel_6"	The area of this slab had to be adjusted so that the thickness fit into the 4" thickness specified in the Impact Estimator (Where the actual thickness is 6"). The following calculation was done in order to determine appropriate Length and Width (in feet) inputs for this slab; = sqrt(Total Sq. feet*(6"/4")) = sqrt[(7738 x (1.5)] = 107.74 feet
	1.2 Concrete Footing		
		1.2.1 FTG_F1	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(4.75’) x (5.5)] / (18”/24)] = 5.90 feet
		1.2.4 FTG_F4	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(4.25’) x (5.0)] / (18”/24)] = 5.32 feet
		1.2.5 FTG_F5	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(4.5’) x (6.0)] / (18”/24)] = 6.0 feet

		1.2.7 FTG_F7	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(4.33’) x (5')] / (18”/24)] = 5.37 feet
		1.2.8 FTG_F8	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(5.75’) x (5.75)] / (18”/24)] = 6.64 feet
		1.2.9 FTG_F9	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(6.33’) x (6.33')] / (18”/24)] = 7.31 feet
		1.2.10 FTG_F10	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(6.33’) x (6.33')] / (18”/24)] = 7.31 feet

		1.2.11 FTG_F11	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(2.5’) x (5')] / (18”/24)] = 4.08 feet
		1.2.12 FTG_F12	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(2.58’) x (2.58')] / (18”/24)] = 2.98 feet
		1.2.13 FTG_F13	The width of this slab was adjusted to accommodate the Impact Estimator limitation of footing thicknesses to be under 19.7”. The measured depth was adjusted to 18" and the average widths and lengths were adjusted to maintain a constant total cubic feet value. = SQRT[(Measured Width) x (Measured Thickness)] / (18/Measured Depth)] =SQRT [(5’) x (6')] / (18”/24)] = 6.32 feet
		Stairs	All Stairs were assumed to be footings, with all required dimnesions being measured
2 Walls	-Since Impact Estimator only alloes for wall thickness inputs of 8" or 12", many of the walls in Neville Scarefe had to be adjusted. Similar to concrete footings, the wall diminesions were altered to maintain the same total cubic footing, while adhering to IE's input criteria. For walls, the height value was held constant, while the length value was adjusted. -Where Vapour Barriers were included, the vapour barrier was assumed to be 6 mil. -Wherever Gypsum board is included, it is being used a surrogate for plaster		
	2.1 Cast In Place		

		2.1.2 Wall_Cast-in-Place_W8_BSMNT_10"	This wall was adjusted by a factor in order to fit the thickness limitations of the Impact Estimator. This was done by either increasing the walls thickness to 10", or decreasing it to 8", depending on which value was closer (in cases of the actual value being in between, the 12" value was used . The length of the wall was then scaled according to the following equation; = (Measured Length) * [(Cited Thickness)/Nominal thickness] = (118') * (10"/12") = 98.3 feet
		2.1.3 Wall_Cast-In-Place_W10_BSMNT_15"	This wall was adjusted by a factor in order to fit the thickness limitations of the Impact Estimator. This was done by either increasing the walls thickness to 10", or decreasing it to 8", depending on which value was closer (in cases of the actual value being in between, the 12" value was used . The length of the wall was then scaled according to the following equation; = (Measured Length) * [(Cited Thickness)/Nominal thickness] = (89') * (15"/12") = 111.25 feet
		2.1.4 Wall_Cast-In-Place_W12_BSMNT_6"	This wall was reduced by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8"] = (156') * [(6")/8"] = 117 feet
		2.1.5 Wall_Cast-in-Place_W11_BSMNT_4"	This wall was reduced by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/8"] = (43') * [(4")/8"] = 21.5 feet

		2.1.6 Wall_Cast-in-Place_W16_GRND_10"	This wall was reduced by a factor in order to fit the 8” thickness limitation of the Impact Estimator. This was done by reducing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (566’) * [(10")/12”] = 472 feet
		2.1.10 Wall_Cast-in-Place_W20_Tunnel_15"	This wall was reduced by a factor in order to fit the 12” thickness limitation of the Impact Estimator. This was done by increasing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (176’) * [(15”)/12”] = 220 feet
		2.1.13 Wall_Cast-in-Place_W23_Tunnel_6"	This wall was increased by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by increasing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (152') * [(6”)/8”] = 114 feet
	2.2 Concrete Block Wall	The dimension of a single Concrete Block in Impact Estimator is measured as 8" thick. Since the Neville Scarfe building has concrete block walls of varying thicknesses, they had to be adjusted to 8". To do so, as with the cast in place walls, the height valu was held constant while the length value was allowed to vary to maintain a constant cubic feet.	
		2.2.2 Wall_ConcreteBlock_W14_BSMNT_6"	This wall was increased by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by increasing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (80') * [(6”)/8”] = 60 feet
		2.2.3 Wall_ConcreteBlock_W13_BSMNT_4"	This wall was increased by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by increasing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (68.4') * [(4”)/8”] =34.2 feet

		2.2.5 Wall_ConcreteBlock_W6_3rd_6"	This wall was increased by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by increasing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (31') * [(6”)/8”] =23.25 feet
		2.2.5 Wall_ConcreteBlock_W6_3rd_6"	This wall was increased by a factor in order to fit the 8" thickness limitation of the Impact Estimator. This was done by increasing the length of the wall using the following equation; = (Measured Length) * [(Cited Thickness)/12”] = (31') * [(6”)/8”] =23.25 feet
	2.3 Hollow Clay Tile	Since no wall input exists for Hollow Clay Tile, Had to include these walls in the Extra Basic Materials Section. Since the thickness of these walls is given as 4" in Impact Estimator, had to adjust all walls accordingly. The input into IE was for the entire surface area of the wall. Also added mortar seperately in XBM, using the relation that there are .0296yd^3 of mortatr /m^2 of wall	
		2.3.1 Wall_Hollow_Clay_Tile_W28_GRND_6"	Since this Wall is 6" thick, we must adjust the wall dimensions to match the IE input of 4" wall according to the following calculation: = (Measured Length*Measured Height)-(# of Doors*Area of door opening) =(121.5' * 9')-6*((32/12)*7)
		Mortar	The amount of Mortar was calculated based on the total square footage of wall inputted. The amount of mortar per square foot was calculated based on the similar input of a brick clad wall in Impact Estimator.
3 Columns and Beams	The method used to measure column sizing was completely depended upon the metrics built into the Impact Estimator. That is, the Impact Estimator calculates the sizing of beams and columns based on the following inputs; number of beams, number of columns, floor to floor height, bay size, supported span and live load. The drawings for the Neville Scarfe building clearly showed the supported span and bay sizes for each beam. Since the bay sizes for the beams between columns was varied, the average value was used, since Impact Estimator only accepts a single bay size value.		
	3.1 Concrete Column		

		3.1.1 Column_Concrete_Beam_N/A_Basement	Since the basement does not have any beams for support, bay and supported span s have been estimated based on the total square foot area of the floor. = sqrt[(Measured Supported Floor Area) / (Counted Number of Columns)] = sqrt[(6597 ft2) / (40)] = 12.84 feet
		3.1.2 Column_Concrete_Beam_Concrete_Ground	Because of the variability of sizes, they were calculated using the following calculation; = sum(Total beam length)/number of columns per beam = sum(31+31+18) / (3) = 27.5 feet
		3.1.3 Column_Concrete_Beam_Concrete_Level2	Because of the variability of sizes, they were calculated using the following calculation; = sum(Total beam length)/number of columns per beam = sum(31+31+18) / (3) = 27.5 feet
		3.1.4 Column_Concrete_Beam_Ground_Level3	Because of the variability of sizes, they were calculated using the following calculation; = sum(Total beam length)/number of columns per beam = sum(31+31+18) / (3) = 27.5 feet
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 only assumptions that had to be made in this assembly group were setting the live load to 75psf, as well as setting the concrete strength 4,000 psi. Neither of these values were given in the drawings for the Neville Scarfe building, and were therefore estimated for the most commonly used.		
5 Roof	The live load was assumed to be 75 psf and the concrete strength was set to 4,000psi. The materials used on the roof were not specifially noted to be one type of roof envelope system. The materials used, however, are consistent with a built up asphalt roofing system with rigid insulation and plaster cover. These were the inputs that went into the Impact Estimator		
	5.1 Concrete Suspended Slab		
		5.1.1 Roof_ConcreteSuspendedSlab_200mm	Polyethylene was assumed to be 6mil.
6 Extra Basic Materials	The main use for extra basic materials in The Neville Scarfe building was to accommodate for materials that did not exist in The impact estimator		

	6.1 Enamel		
		6.1.1 XBM_Cladding_Enamel	Enamel was used in the building as a cladding material on both the front and the rear faces of the building. The total area of the enamel was simply measured using OnScreen takeoff. The alternative material used for enamel was standard cladding
	6.2 Brick		
		6.1.2 XBM_Cladding_Glazed Brick	Used for two purposes: 1) Used as a surrogate for the hollow clay tile wall that was commonly used as a partition wall in the Neville Scarfe building. 2) Used as a cladding material for the "Glazed Brick" found on parts of the building. Had to add in mortar seperately to XBM, where the amount of mortat= .0296yd^3 per 1 ft^2 Used Modular Metric Brick input
	6.3. Tile		
		6.1.23 XBM_Cladding_Mosaic Tile	Mosaic Tiles were used on the Neville Scarfe building as aesthiteic effects. The surrogate used was also modular brick. The area of the mosaic tiles was measured and entered into the Impact Estimator.