MATERIAL SUSTAINABILITY

EVALUATING THE ENVIRONMENTAL IMPACTS OF BUILDING MATERIALS

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ACKNOWLEDGMENTS

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ABSTRACT

This project aims to reconcile the existing environmental impact tools with current MSR material research to develop a methodology that can be used by the firm, in conjunction with designers and clients, to make educated material decisions that satisfy the needs for the circumstance, human health, and environment.
INTRODUCTION

MSR has the desire to make material choices that take environmental and health impacts into account. Through researching the current state of LCA tools and applying them to two MSR projects, a methodology for material selection will be developed. This methodology should not only facilitate material decision making, but should also fit into MSR’s design process and unique character in order to ensure its use and success. Existing LCA tools will be examined to determine their capabilities, limitations, and how they fit into the design process. These tools focus heavily on environmental impacts and tend to be less effective in measuring health hazards and responsible sourcing; therefore, findings from these tools should be paired with other resources to help make the best decisions for both clients and designers. MSR is currently undergoing material research relating to human health impacts; this research will be folded into the initiative to create a comprehensive process for responsible material selection.

Through this research project, BEES, Athena, and Tally Environmental Impact Estimator will be examined and used in tandem with other material and product resources to create a process that can be used by the firm, in conjunction with designers and clients, to make educated material decisions that satisfy the needs for the environment, human health, and circumstance.
RESEARCH OUTLINE

Goals
Help designers make informed materials choices
Ensure the methodology is easy to use
Produce graphical output that facilitates an understanding and a discussion of results

Contextual Issues
What are the critical issues of sustainable material choices?
What is the current state of environmental impact estimator tools?
What are the capabilities and limitations?
How can the 2030 Challenge for Products be folded into the materials methodology?

Methodology
Create a process by examining the Itasca Biological Research Station and Laboratory with the LCA tools. Through this, limitations and capabilities of the tools will become evident.
Apply the developing material analysis and impact assessment process to Aeon South Quarter IV to compare results between the two projects.
Analyze Itasca and Aeon comprehensively (i.e., Whole Building Analysis) as well as breaking the analysis down into assemblies: walls, floors, and roofs.
Develop a template for assembly types to create an ever-expanding database to be used as reference for the office.
Demonstrate how the process can be used in the office.

References
Life Cycle Assessment: Principles and Practice. 1
AIA Guide to LCA. 2
Architecture 2030 3
AIA 2030 Commitment: Measuring Industry Progress Toward 2030. 4

Tools
BEES (Building for Environmental and Economic Sustainability)
Athena Impact Estimator
Tally Environmental Impact Estimator
DEFINING THE ISSUES

IMPACT OF MATERIALS + PRODUCTS

According to Architecture 2030, the building sector is responsible for 49% of Annual U.S. Energy Consumption. Of this 49%, building products and manufacturing make up 5-8% of the total energy consumption.3

As buildings become more efficient from an operational standpoint, the embodied energy of building products and materials becomes more critical.
EMBODIED ENERGY VERSES EUI

*Embodied Energy:*
The embodied energy (carbon) of a building material or product, which is expressed as the primary energy consumed, or carbon released over its life cycle, from extraction to end of life. Total embodied energy can also be classified by renewable energy and non-renewable energy.

Non-renewable energy: energy derived from fossil fuels such as petroleum, natural gas, and coal
Renewable: energy from other sources such as hydropower, wind, nuclear, geothermal, biomass

*EUI:*
EUI is a measure of the operational energy of a building and is generally expressed as energy per square foot per year. It’s calculated by dividing the total energy consumed by the building in one year (measured in kBtu or GJ) by the total gross floor area of the building.
On day one of a building’s occupation, 100% of the energy is embodied - embodied energy of the materials and products used in its construction. Over time, the operational energy adds up, eventually meeting the total embodied energy of the building.

The relationship between Embodied Energy and EUI is complex. For an efficient building with a low EUI and a high Embodied Energy, the number of years for the EUI to catch up to the Embodied Energy will be higher than for a less efficient building. However, the high Embodied Energy associated with an efficient building typically comes from the ample amounts of insulation required for its operational efficiency. While a definitive conclusion cannot be drawn between the Operational and Embodied Energy, it is a window into the energy use of buildings, and a way to begin to understand the complex situation.

Figure 2
The relationship between embodied energy and operational energy

Embodied Energy (Typical Residence)
Over the first 20 years of the life of a building (from today until 2030), 45% of total energy consumption is attributed to the embodied energy of building products and 55% is attributed to building operations.

Source: ©2011 2030 Inc./Architecture 2030. All Rights Reserved.
Data Source: EIA (2011), Richard Stein
IMPACT OF MATERIALS

Understanding the environmental and health impact of materials can be difficult due to the abstract nature; it is hard to comprehend exactly what Eutrophication, for example, means to the common individual. The various impacts affect different zones and systems to varying degrees. Some impacts may remain contained within a local area, whereas others have a global impact. In addition, the impacts can affect more than one area, for instance, an impact affecting the regional environment may also spill over to affect the global environment.

Below is a diagram containing a multitude of impact categories as well as their associated impact zone.

GLOBAL IMPACTS:
- Global Warming Potential: polar melt, soil moisture loss, longer seasons, forest loss/change, and change in wind and ocean patterns
- Ozone Depletion: increased ultraviolet radiation
- Resource Depletion: [ie fossil fuel depletion] decreased resources for future generations

REGIONAL IMPACTS:
- Photochemical Smog: “smog,” decreased visibility, eye irritation, respiratory tract and lung irritation, vegetation damage
- Acidification: building corrosion, water body acidification, vegetation effects, and soil effects.

LOCAL IMPACTS:
- Human health: increased morbidity and mortality
- Habitat Alteration + Ecotoxicity
- Terrestrial Toxicity: decreased production and biodiversity and decreased wildlife for hunting or viewing
- Aquatic Toxicity: decreased plant and insect production and biodiversity and decreased commercial or recreational fishing
- Eutrophication: nutrients (phosphorous and nitrogen) enter water bodies, such as lakes, estuaries, and slow-moving streams, causing excessive plant growth and oxygen depletion
- Land Use: loss of terrestrial habitat for wildlife and decreased landfill space
- Water use: loss of available water from groundwater and surface water sources.
**IMPACT OF MATERIALS**

**PRIMARY ENERGY DEMAND**
- Regional
- Global
- Local
A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.

**GLOBAL WARMING POTENTIAL**
- Global
A measure of greenhouse gas emissions, such as CO2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health, and material welfare.

**ACIDIFICATION POTENTIAL**
- Regional
- Local
A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule’s capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.

**OZONE DEPLETION POTENTIAL**
- Global
A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth’s surface with detrimental effects on humans and plants.

**SMOG FORMATION POTENTIAL**
- Local
Ground level ozone is created by various chemical reactions, which occur between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues including increasing symptoms of bronchitis, asthma,
and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage. The primary sources of ozone precursors are motor vehicles, electric power utilities, and industrial facilities.

**EUTROPHICATION POTENTIAL**
- **Local**

Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.
### Human Health

<table>
<thead>
<tr>
<th>Impact</th>
<th>Global, Regional, Local</th>
<th>Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ozone Depletion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levels of UVB ultraviolet rays reaching the earth’s surface with detrimental effects on humans and plants. A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher consumption of oxygen in biomass decomposition. Terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems.</td>
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<tr>
<td><strong>Eutrophication</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P).</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Acidification</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule’s capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Global Warming Potential</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A measure of greenhouse gas emissions, such as CO₂ and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health, and material welfare.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Embodied Energy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary Energy Demand</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g., petroleum, natural gas, etc.) and energy demand from renewable resources (e.g., hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g., power, heat, steam, etc.) are taken into account.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Habitat Alteration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measures the potential for land use by humans to lead to damage of threatened and endangered species. Based on TRACI Impact assessment, the density of endangered or threatened species is used as a proxy for the degree to which the use of land may lead to undesirable changes in habitats. Does not consider original condition of land, extent to which human activity changes the land, or the length of time required to restore the land to its original condition.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Criteria Air Pollutants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A measure of air quality based on the concentrations of particles and gases that can harm human health. These criteria pollutants are: coarse particles known to aggravate respiratory conditions such as asthma, and fine particles that can lead to more serious health outcomes. Cause: Combustion, vehicle operation, power generation, materials handling, and crushing and grinding operations. Criteria air pollutants are solid and liquid particles commonly found in the air. Method involves measuring pollutant concentrations from industrial sources as well as the potential of these pollutants to harm ecosystems.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Smog</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ground level ozone is created by various chemical reactions, which occur between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage. The primary sources of ozone precursors are motor vehicles, electric power utilities, industrial processes, and natural sources such as lightning. Ground level ozone is often referred to as smog.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Noncancer</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule’s capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Indoor Air Quality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A measure of the quality of indoor air in relation to human health. In the absence of reliable characterization factors, a product’s total volatile organic compound (VOC) emissions are often used as a measure of indoor air performance.</td>
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<td></td>
</tr>
</tbody>
</table>

### Embodied Energy

<table>
<thead>
<tr>
<th>Impact</th>
<th>Global, Regional, Local</th>
<th>Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global Warming Potential</strong> [kg CO₂ eq]</td>
<td>Global</td>
<td>Air</td>
</tr>
<tr>
<td>A measure of greenhouse gas emissions, such as CO₂ and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health, and material welfare.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fossil Fuel Consumption</strong></td>
<td>Global, Regional, Local</td>
<td>Air</td>
</tr>
<tr>
<td>Quantity of minerals used and quantity of fossil fuels used. The quantity of fossil fuels used in all stages of the life cycle. This impact addresses only the depletion aspect of fossil fuel extraction, not taking into account potential impacts from the extraction itself. Extraction impacts, such as methane emissions from coal mining are addressed in global warming potential. Measures the amount of energy required to extract a unit of energy from consumption changes over time.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Primary Energy Demand</strong> [MJ (lower heating value)]</td>
<td>Renewable</td>
<td>Non-renewable</td>
</tr>
<tr>
<td>A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g., petroleum, natural gas, etc.) and energy demand from renewable resources (e.g., hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g., power, heat, steam, etc.) are taken into account.</td>
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<td></td>
</tr>
</tbody>
</table>

### Other Impacts

<table>
<thead>
<tr>
<th>Impact</th>
<th>Regional, Local</th>
<th>Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acidification</strong> [kg SO₂ eq]</td>
<td>Regional, Local</td>
<td>Air, Water</td>
</tr>
<tr>
<td>A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule’s capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Eutrophication [kg N eq]  
Local  
Air, Water

Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.

### Ozone Depletion [kg CFC-11 eq]  
Global  
Vegetation, soil

A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth’s surface with detrimental effects on humans and plants.

### Smog [kg O3 eq]  
Local  
Air

Ground level ozone is created by various chemical reactions, which occur between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage. The primary sources of ozone precursors are motor vehicles, electric power utilities, and industrial facilities.

### Ecotoxicity  
Local  
Urban Air, Nonurban Air, Freshwater, Seawater, Natural Soil, Agricultural Soil

This measures the potential of a chemical released into the environment to harm terrestrial and aquatic ecosystems. Method involves measuring pollutant concentrations from industrial sources as well as the potential of these pollutants to harm ecosystems.

### Water Intake  
Global, Regional, Local  
Water

The quantity of water used or consumed. Impact only addresses the depletion aspect of water intake, and does not factor in potential associated water pollution.

### Land Use  
Global, Regional, Local  
Natural Soil, Agricultural Soil

Quantity disposed of in a landfill or other land modifications

### Habitat Alteration  
Regional, Local  
Air

Measures the potential for land use by humans to lead to damage of threatened and endangered species. Based on TRACI Impact assessment, the density of endangered or threatened species is used as a proxy for the degree to which the use of land may lead to undesirable changes in habitats. Does not consider original condition of land, extent to which human activity changes the land, or the length of time required to restore the land to its original condition.

### Criteria Air Pollutants  
Regional, Local  
Air

Criteria air pollutants are solid and liquid particles commonly found in the air.  
Cause: Combustion, vehicle operation, power generation, materials handling, and crushing and grinding operations.  
Include: coarse particles known to aggravate respiratory conditions such as asthma, and fine particles that can lead to more serious respiratory symptoms and disease.
EVALUATING MATERIALS
LIFE CYCLE ASSESSMENT

Life cycle assessment: Can either be cradle to grave (material extraction to disposal) or cradle to gate (material extraction through manufacture)

While numerous LCA tools exist, the effective undertaking of an LCA is usually something undertaken by an expert. However, with the tools available, designers can choose the level of detail they desire to achieve and make quick materials comparisons.

LCA provides opportunity to:

- Develop systematic evaluation of the environmental consequences associated with a given product
- Analyze the environmental trade-offs associated with one or more specific products/processes to help gain stakeholder (state, community, etc) acceptance for a planned action
- Quantify environmental releases to air, water, and land in relation to each life cycle stage and/or major contributing process
- Assist in identifying significant shifts in environmental impacts between life cycle stages and environmental media
- Assess the human and ecological effects of material consumption and environmental releases to the local community, region, and world
- Compare the health and ecological impacts between two or more rival products/processes or identify the impacts of a specific product or process
- Identify impacts to one or more specific environmental areas of concern
Figure 1
Life Cycle Assessment Types

Cradle-to-Grave
Full LCA
Manufacture
Use
Disposal

Cradle-to-Gate
Partial LCA
Manufacture
To Factory

Cradle-to-Cradle
Specific type of cradle-to-crade
End of life disposal is a recycling process

Gate-to-Gate
Partial LCA
Looks only at one value-added process
EVALUATING MATERIALS
LCA PROCESS

“The use of LCA for buildings requires a set of guiding principles, which consider the unique character of each building design, complexity in defining systems, and related decisions.”

When conducting any life cycle assessment, both the designer and LCA tool play crucial roles. At the onset of the study, the designer must establish the goal and scope. It is easy for LCAs to get unmanageable rather quickly due to the number of impact categories and materials in question. Therefore, defining the goal and scope of the study enables the designer to focus the investigation.

The LCA tool handles the blunt of the work: Inventory Analysis and Impact Assessment. This is the stage where designers input the information to be analyzed and allow the tool to do the calculations.

Lastly, but more importantly, the interpretation of the results. Again, this is where the original goal and scope can come in handy to aid designers in interpreting the multitude of outputs. The narrower or more focuses the line of inquiry, the easier it is to interpret results in order to make a decision.

Each of these steps are related and can be altered along the way, as well as be adapted for different stages in the design process.
Goal + Scope

- Establishes the purpose of the study and its breadth and depth
- Defines the boundaries of the product system under study

Inventory Analysis

- Identifies and quantifies the environmental inputs and outputs associated with a product over its entire life cycle (inventory flows)
- Inputs:
  - Water
  - Energy
  - Land
  - Other Resources
- Outputs:
  - Releases to air, land, and water

Impact Assessment

- Characterizes these inventory flows in relation to a set of environmental impacts
- Impact assessment step may relate carbon emissions (a flow) to global warming (an impact)

Interpretation

- Combines the environmental impacts in accordance with the goals of the LCA study
- Arranges or represents the results in accordance with established goals or hierarchy
EVALUATING MATERIALS
RESEARCH PROCESS

Similar to any research endeavor, this process began erratically and has slowly become more concise. At the onset of the research the investigation included three different LCA tools (BEEs, Athena, and Tally) as well as all impact categories. This resulted in a plethora of outputs, varying inputs, and an unclear strategy for interpretation.

Through the process, Tally Environmental Impact Tool was chosen as the sole tool to carry forward. This simplified the process by eliminating multiple outputs, additional time, and discrepancies. Moving forward, the process can be approached with a clear issue or line of inquiry allowing the designer to isolate specific impact areas to monitor.

The resulting workflow and database that was developed serves as both a point of reference as well as a strategy for testing future assemblies, materials, as well as conducting a full building analysis.

A template was designed using outputs from Tally that allows all relevant material pertaining to a specific assembly to be presented in a clear manner. This is the beginning of an assembly database that can serve as reference for future projects as well as continue to grow.

Figure 1
Research and tool process diagram.
Human Health
- Cancer
- Noncancer
- Indoor Air Quality
- Smog
- Criteria Air Pollutants

Embodied Energy
- Global Warming Potential
- Fossil Fuel Consumption
- Primary Energy Demand
- Non-renewable

Other Impacts
- Acidification
- Ozone Depletion
- Smog
- Indoor Air Quality
- Land Use

Decision

Interpretation

Tool Output

Issue

Tally

Interpretation

Decision
EVALUATING MATERIALS
LCA TOOLS

The three tools have their own unique characteristics, capabilities and strengths. How the tools operate, or how they can be used varies. BEES is one-dimensional; products or materials can be selected to be compared to a similar material. Outputs can be viewed within the web browser, but it is not suitable for more complex analysis. Athena is two-dimensional; assemblies can be built and analyzed as a whole. For instance, a wall assembly can be constructed and impact outputs can be viewed relating to that assembly. Tally is three-dimensional; as a Revit plug in, it operates from geometry modelled in Revit, providing a visual representation of the geometry being studied. Tally also provides the opportunity for whole building analysis, assembly analysis as well as down to individual material analysis.
LCA TOOLS

**BEES**
- Athena Tally
- Database: 1200+ materials, 800 material entries, 19,000 permutations possible
- Quick Material/product comparison
- Assess Impacts between options
- Whole building assessment
- Assembly assessment
- Simple wall impact assessment
- Compare options
- No building visualization

**Athena**
- 230+ products
- 1200+ materials
- Whole building assessment
- Assembly assessment
- Accurate sq. footage + geometry
- Easy option comparison
- 3D model visualization

**Tally**
- 800 material entries - 19,000 permutations possible
- Whole building assessment
- Assembly assessment
- Accurate sq. footage + geometry
- Easy option comparison
- 3D model visualization

Direct Comparison
EVALUATING MATERIALS
LCA TOOLS: BEES
[Building for Environmental and Economic Sustainability]

BEES is a web-based LCA tool for building products. It provides easy comparison of multiple products or materials such as insulation, cladding, or finish materials. While it is an effective tool, its database is the most limited of the three tools investigated.

Overview
- Decision making web-based tool that provides assessment of building products.
- Impacts can be weighted using pre-defined weights, or user-defined.
- Results can be viewed in summary, or broken down into Life Cycle Flows, Embodied Energy
- Linked to BEES 4.0 LCA databases

Methodology:
- Multidimensional, life-cycle approach; multiple environmental and economic impacts over the entire life cycle of product

Using BEES: User Inputs
- Desired Weighting or none
- Product type/specific
- May select multiple to compare
- Distance product must travel

Outputs: Software-Generated Graphs + Chart
- Summary
- Economic
- Environmental (only available if weighted outputs selected
- Life Cycle Stage [by impact category]
- Environmental Flow [by impact category]
- Embodied Energy [by Fuel Renewability and Fuel Usage]
Impact Categories:
- Global Warming
- Acidification
- Human Health
- Indoor Air Quality
- Ozone Depletion
- Smog
- Eutrophication
- Fossil Fuel Depletion
- Water Intake
- Ecotoxicity
- Criteria Air Pollutants
- Habitat Alteration

**BEES**

Database: 230+ products

Capabilities/
Strengths
- Quick Material/product comparison
- Assess Impacts between options
EVALUATING MATERIALS
LCA TOOLS: ATHENA IMPACT ESTIMATOR

Athena Impact Estimator is a free LCA software provided by the Athena Institute. It allows the user to built assemblies (wall, floor, roof and structure) to calculate the environmental and health impacts associated with them. While Athena is capable of whole building analysis, the interface is not as intuitive as Tally. There is no visual feedback of what the user is constructing. However, it is an extremely useful free tool.

Overview
- Decision making software that compares environmental implications of designs.
- Results take into account all LCA stages. Link to Athena LCA databases.
- Methodology from input to output

Using Athena Impact Estimator: User Inputs
- Location
- Building Type, Expected Service Life, Owner Occupied/Rental

Software-Generated Bill of Materials
- Prescriptive Quantity Take-off
- Deterministic Quantity take-off
- Import Bill of Materials

Inner Workings of the Software
- Regional considerations
- On-site construction effects
- Maintenance, repair, and replacement effects
- End of Life Effects

Outputs: Impact Categories
- Global Warming Potential
- Acidification Potential
- Human Health Respiratory Effects Potential
- Ozone Depletion Potential
- Photochemical Smog Potential
- Eutrophication Potential
- Fossil Fuel Consumption
Athena

Database:
- 1200+ materials

Capabilities/Strengths:
- Whole building assessment
- Assembly assessment
- Simple wall impact assessment
- Compare options
- No building visualization

LCA TOOLS
BEES Athena Tally

Direct Comparison vs vs vs 230+ products

Database:
Capabilities
Strengths
- 1200+ materials
- 800 material entries - 19,000 permutations possible
- Quick Material/product comparison
- Assess Impacts between options
- Whole building assessment
- Assembly assessment
- Simple wall impact assessment
- Compare options
- No building visualization
EVALUATING MATERIALS  
LCA TOOLS : TALLY ENVIRONMENTAL IMPACT TOOL

Tally Environmental Impact Tool is a Revit plug in developed by KieranTimberlake, PE International, and Autodesk. It is the newest of the LCA tools under study. As a Revit plug in, it has many advantages. For one, as the industry shifts to using Revit throughout the design process, the plug in eliminates the need to build an additional model for analysis. In addition, unlike the other LCA tools, Tally’s interface with Revit provides a three-dimensional visual for the building or assembly in question. The specific geometry, sizing, and assembly can be seen by the user and is ensured to be factored into the calculation.

Tally is a powerful tool, capable of whole building analysis, assembly analysis, as well as individual material or product analysis. In addition, the tool has built in Option Comparison Analysis which interfaces with Revit. This enables quick and easy comparisons between different material options such as cladding or insulation.

Overview
- LCA plug in for Revit that allows whole building analysis or comparison analysis of building assemblies
- Three dimensional, take off from Revit; user defined assemblies bridges the gap between what is modelled and what is analyzed
- Results take into account all LCA stages. Link to Tally databases

Using Tally: User Inputs
- Define building assembly
- Building type, expected service life

Software-Generated Bill of Materials
- Prescriptive Quantity Take-off
- Deterministic Quantity take-off
- Import Bill of Materials

Inner Workings of the Software
- On-site construction effects
- Maintenance, repair, and replacement effects
- End of life effects

Outputs: Impact Categories
- Global Warming
- Acidification
- Ozone Depletion
- Smog Formation
- Eutrophication
- Primary Energy Demand
- Non-renewable Energy
- Renewable Energy
**LCA TOOLS**

**BEES Athena Tally**

**Capabilities**
- 1200+ materials
- 800 material entries - 19,000 permutations possible

**Strengths**
- Quick Material/product comparison
- Assess Impacts between options
- Whole building assessment
- Assembly assessment
- Simple wall impact assessment
- Compare options
- No building visualization

**Database:**
- 800 material entries - 19,000 permutations possible

**Results per CSI Division, itemized by Tally™ Entry**

<table>
<thead>
<tr>
<th>Division</th>
<th>Material</th>
<th>Description</th>
<th>Unit</th>
<th>Global Warming Potential</th>
<th>Primary Energy Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>03 - Concrete</td>
<td>Cast-in-place concrete, reinforced structural concrete, 5000 psi (35 Mpa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>04 - Masonry</td>
<td>Hollow-core CMU, grouted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>06 - Wood/Plastics/Composites</td>
<td>Laminated veneer lumber (LVL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>07 - Thermal and Moisture Protection</td>
<td>Closed cell, polyurethane foam, spray-applied</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>08 - Finishes</td>
<td>Exterior insulation and finish system (EIFS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td></td>
<td>Extruded polystyrene (XPS), board</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td></td>
<td>Fiber cement siding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td></td>
<td>Fluid applied elastomeric air barrier</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>09 - Finishes</td>
<td>Mineral wool, board</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**
- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Finishes
- 09 - Finishes

**Direct Comparison**

- Whole building assessment
- Assembly assessment
- Accurate sq. footage + geometry
- Easy option comparison
- 3D model visualization
EVALUATING MATERIALS
LCA TOOLS: COMPARISON MATRIX

All three LCA tools are valuable, but each possesses certain capabilities, strengths and weaknesses. Depending on the focus of the line of inquiry a specific tool may work more effectively than another. Below is a matrix comparing the three tools.
## Athena Impact Estimator

<table>
<thead>
<tr>
<th>TOOL DEVELOPER</th>
<th>Athena Institute</th>
<th>NIST</th>
<th>KieranTimberlake + Autodesk Sustainability Solutions + PE INTERNATIONAL</th>
</tr>
</thead>
</table>

### Factors + Units

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming Potential</td>
<td>Global Warming [grams of CO2 equivalent per functional unit]</td>
<td>Acidification [grams of hydrogen ion equivalent per functional unit]</td>
<td>Human Health [PM2.5 Equivalent Mass]</td>
</tr>
<tr>
<td>Indoor Air Quality Cancer</td>
<td>Indoor Air Quality Cancer</td>
<td>Noncancer</td>
<td>Noncancer</td>
</tr>
<tr>
<td>Ecotoxicity (grams of 2, 4-D per functional unit)</td>
<td>Ecotoxicity (grams of 2, 4-D per functional unit)</td>
<td>Eutrophication Potential [grams of nitrogen per functional unit of product]</td>
<td>Ozone Depletion [CFC11 equivalent] Ecotoxicity (grams of 2, 4-D per functional unit)</td>
</tr>
<tr>
<td>Habitat Alteration (threatened and endangered species count per functional unit of product)</td>
<td>Habitat Alteration (threatened and endangered species count per functional unit of product)</td>
<td>Ozone Depletion [CFC11 equivalent] Habitat Alteration (threatened and endangered species count per functional unit of product)</td>
<td>Ozone Depletion [CFC11 equivalent] Habitat Alteration (threatened and endangered species count per functional unit of product)</td>
</tr>
</tbody>
</table>

### Life-Cycle Stages Included

<table>
<thead>
<tr>
<th>Material Extraction and Manufacturing</th>
<th>Material Extraction and Manufacturing</th>
<th>Material Extraction and Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related Transportation</td>
<td>Related Transportation</td>
<td>Related Transportation</td>
</tr>
<tr>
<td>On-site Construction (energy use + related emissions)</td>
<td>On-site Construction (energy use + related emissions)</td>
<td>On-site Construction (energy use + related emissions)</td>
</tr>
<tr>
<td>Operation (energy only)</td>
<td>Operation (energy only)</td>
<td>Operation (energy only)</td>
</tr>
<tr>
<td>Replacement</td>
<td>Replacement</td>
<td>Replacement</td>
</tr>
<tr>
<td>Demolition and Transport to Landfill</td>
<td>Demolition and Transport to Landfill</td>
<td>Demolition and Transport to Landfill</td>
</tr>
<tr>
<td>Recycling and Waste Management</td>
<td>Recycling and Waste Management</td>
<td>Recycling and Waste Management</td>
</tr>
<tr>
<td>Disposal or Recycling</td>
<td>Disposal or Recycling</td>
<td>Disposal or Recycling</td>
</tr>
</tbody>
</table>

### LCA Tool Type

| Whole Building Analysis Tool | Building Product LCA Tool | Whole Building Analysis Tool Assembly Comparison Tool |

### Building Material/Assembly

| 1,200+ | 210+ | 800 material entries - 19,000 permutations possible - growing |

### Cost

| $0 | $0 | $1,200/year |
EVALUATING MATERIALS
OFFICE HIERARCHY

Due to the complex nature of LCA and evaluating materials, a hierarchy was created for MSR, outlining what was of most importance to the office. As was outlined previously, each of the tools possesses a set of strengths, while they may be lacking in other areas. In order to address a complex set of issues, other resources may need to be referenced to gather the appropriate information.

LCA tools primarily focus on Environmental impacts, leaving a void in the information as it relates to Human Health. Due to this inefficiency, other resources should be consulted where Human Health is concerned. In the case of MSR, the office has been conducting extensive research pertaining to the human health impact of materials in relation to the Living Building Challenge and the Declare Red List.

Other resources exist such as the Perkins+Will Transparency List, Pharos, and GreenSpec.

Below is a diagram relating the environmental and human health impacts and which tools or reference databases cover each specific category. While the LCA tools may cover human health impacts, the outputs will not be as extensive as other resources.
**Human Health**
- Cancer
- Noncancer
- Indoor Air Quality
- Smog
- Criteria Air Pollutants

**Embodied Energy**
- Global Warming Potential
- Fossil Fuel Consumption
  - Primary Energy Demand
    - Non-renewable
    - Renewable

**Other Impacts**
- Acidification
- Chlone Depletion
- Eutrophication
- Freshwater
- Water Intake
- Habitat Alteration
- Land Use
- Global Warming Potential
- Fossil Fuel Consumption
- Primary Energy Demand
- Non-renewable
- Renewable

**Tools**
- Human Health Declaration (HPD)
- DECLARE
- P+W Transparency
- BEES
- Athena
- Tally
- Environmental Product Declaration (EPD)
- Cradle-to-Cradle Products
PROCESS
PROCESS + TEST METHOD

In order to test the capabilities, ease of use, and workflow of each of the LCA tools, Itasca Biological Research Station and Laboratories (a MSR project currently under construction) was used as a test project. Rather than jumping directly into a full building analysis, the wall assemblies from Itasca were isolated and analyzed using the tools. Right off the bat, BEES proved problematic. The tool is meant to compare individual materials or products rather than analyzing an assembly. This study resulted in a massive spread sheet, recording outputs for each individual material. It was quickly decided that BEES was not the tool for this particular line of inquiry and was subsequently dropped.

Athena and Tally however, were able to run similar sets of analysis for the wall assemblies. To ensure a level of consistency between inputs and outputs, a 10 foot by 15 foot wall was modelled in each tool. In Athena, this consisted of creating a file or project for each associated wall type and getting outputs individually. Tally on the other hand could be approached in multiple ways. There was one file with each of the Itasca wall types loaded into the file. The analysis could then either be run as a Design Option Comparison, resulting in the impacts of each wall being displayed in direct relationship to the others, or a Whole Building Analysis of each individual wall. Overall, the process and interface associated with Tally is much friendlier and less time consuming than that of Athena.

DATABASE LIMITATIONS

As all of the tools come equipped with different LCA databases associated with them, there is a certain level of inaccuracy. However, any LCA conducted has a level of uncertainty. This was tracked through a matrix of inputs. The actual wall assembly was noted, along with the material available within the tool database. If the actual material was not available, a the closest possible alternative was used in its place. While not yielding perfect results, this method is still very effective.
Constants:
Wall Area: 150 sq ft
Building Life Expectancy: 60 years

Results per functional unit
- no specific geometry

Per product:
Fiber Cement Panel = #
Sheathing = #
Stud Wall = #
CMU = #
Insulation = #

+ BEES + Athena + Tally +
PROCESS
HOW THE TOOLS WERE USED
DATABASE LIMITATIONS

As stated previously, each of the tools are equipped with different databases. These range from generic materials to specific manufacturers. As the databases grow and more manufacturers submit information, the information will become more available and expansive.

In their current state, each of the tools varies in what is contained in the database. Through testing, the inputs were tracked to map the actual wall assembly in comparison to what was input in each tool. An example of this matrix can be seen below.

However, in moving forward, this exercise was dropped for a couple of reasons. One, in shifting to using solely Tally, this tracking seemed less effective or necessary, and two, it is time consuming., and thus hinders the process.

It is to be understood that all LCA information is not 100% accurate.

Figure 1
Tracking database material availability + inputs
### Assembly

<table>
<thead>
<tr>
<th>Wall 1</th>
<th>BEES</th>
<th>ATHENA IMPACT ESTIMATOR</th>
<th>TALLY IMPACT ESTIMATOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/8&quot; GWB</td>
<td>Generic Gypsum Board</td>
<td>Gypsum Regular 5/8&quot;</td>
<td>Wall Board, gypsum, natural</td>
</tr>
<tr>
<td>3-1/2&quot; INSUL-4</td>
<td>Mineral fiber blanket insulation R-13</td>
<td>Mineral Wool Batt R11-15 (3-1/2&quot;)</td>
<td>Rockwool insulation, low density</td>
</tr>
<tr>
<td>3-3/4&quot; INSUL-3</td>
<td>Closed cell polyurethane spray foam</td>
<td>X</td>
<td>Polyisocyanurate Foam (3-3/4&quot;)</td>
</tr>
<tr>
<td>SHTG: 3-1/2&quot;</td>
<td>Exterior Wall Sheathing</td>
<td>Generic Plywood</td>
<td>Put in 2 layers of Gypsum Moisture Resistant 1/2&quot; boards</td>
</tr>
<tr>
<td>ARBB-1</td>
<td>Fluid applied air barrier, vapor permeable</td>
<td>X</td>
<td>Air Barrier</td>
</tr>
<tr>
<td>2&quot; INSUL-7</td>
<td>Semi-rigid mineral fiberboard insulation R-10</td>
<td>Generic Blown Mineral Wool R-13</td>
<td>Mineral Wool Batt R11-15 (2&quot;)</td>
</tr>
<tr>
<td>1&quot; INSUL-7</td>
<td>Semi-rigid mineral fiberboard insulation R-7.5</td>
<td>Generic Blown Mineral Wool R-13</td>
<td>Mineral Wool Batt R11-15 (1&quot;)</td>
</tr>
<tr>
<td>SIDE-1</td>
<td>SIDE-1: Hardie lap siding</td>
<td>CertainTeed Weatherboards Siding</td>
<td>Fiber Cement siding</td>
</tr>
<tr>
<td>SIDE-2</td>
<td>SIDE-1: Hardie vertical siding</td>
<td>CertainTeed Weatherboards Siding</td>
<td>Fiber Cement siding</td>
</tr>
<tr>
<td>WD Ms</td>
<td>Laminated Veneer Lumber</td>
<td>Generic Wood Framing – treated</td>
<td>Wood Stud</td>
</tr>
</tbody>
</table>
PROCESS
HOW THE TOOLS WERE USED

After the preliminary testing involving all three LCA tools, it was decided that Tally was the more efficient, easiest to use, and generally more appealing tool. The major aspect working in Tally's favor is that as a Revit plug in, it does not require the creation of an additional model for analysis. The exchange between Revit and Tally is relatively seamless, the interface is user friendly, and it's database is one of the largest and still growing. While it is not a free tool like BEES or Athena, it is the most effective tool on the market. Tally can be used to easily tackle a range of different levels of analysis, from whole building analysis, to assemblies, and down to individual materials. It essentially does what the other tools do plus some.
Phase 1

BEES + Athena + Tally

Phase 2

BEES + Athena + Tally

Figure 1
Phases of tool use + process

Full Building Analysis

3D

height: 15'

10'

3D

VS

VS

Isolating Wall Assemblies

Isolating Materials
PROCESS
HOW THE TOOLS WERE USED: TALLY

In moving forward with Tally as the sole LCA tool, a strategy was developed to analyze two MSR projects: Itasca Biological Research Center and Laboratories and Aeon South Quarter IV. The analysis would look at whole building assessment, assemblies (wall, floor, roof) and individual materials.

In addition to examining the projects at different levels, a database of assemblies and their impacts was begun, with the intention of it continuing to grow over time.
**TALLY Capabilities**

**WALL ASSEMBLIES**
- Assembly assessment
- Design Option Comparison
- Assemble wall type database

**INDIVIDUAL MATERIALS**
- Quick material/product comparison
- Assess Impacts between options
- Design Option Comparison

**WHOLE BUILDING**
- Whole building assessment
- Accurate sq. footage + geometry
- Easy option comparison
- 3D model visualization
- Design Option Comparison

---

**Capabilities**
- Whole building assessment
- Accurate sq. footage + geometry
- Easy option comparison
- 3D model visualization
- Design Option Comparison

---

**Direct Comparison**
DATABASE DEVELOPMENT

In constructing the database, initially the intention was to delve into all of the subcategories: roofs, floors, walls, structure, and glazing. However, upon undergoing the whole building analysis it was discovered that the building categories that carry the most weight in terms of environmental impacts are the walls, roofs, and floors. Therefore, the focus shifted to these assemblies.

As can be seen below, the areas with the largest impacts are roofs, floors, and walls -- these categories are responsible for significantly higher percentages of the total impacts compared to other systems such as glazing, mullions, or windows.

In the Aeon project, the walls account for almost half of the environmental impacts (in relation to embodied energy and global warming potential), with the floors coming in around a quarter, and the roof around one-tenth.

In Itasca, the walls account for around forty-percent of the total impacts, with floors around twenty-percent, and the roofs from twenty four to thirty-seven percent. This clearly shows which assemblies are responsible for the largest environmental impacts, and thus, which areas should be focused on in the design process.

Figure 1
Whole building assessment outputs by assembly type: walls, roof, floor, etc

AEON

ITASCA
Figure 1
Database development thought process - which assemblies to include
DATABASE
TEST METHOD

The development of the database and its associated template began with analyzing the wall assemblies of both Itasca and Aeon. Once the additional systems were identified (floors and roofs), the template could be designed to accommodate all of these systems in the same manner. The wall, floor or roof area was kept consistent through all tests so that the results could be cross compared.

The dimensions of each are as such:
Wall: 10’x15’ / area: 150 sq ft
Roof: 10x10 / area: 125 sq ft
Floor: 10’x10’ / area: 100 sq ft
The Whole Building can be divided into three parts:

- **Walls**
  - Area: 150 sq ft
  - Dimensions: 15' x 10' x 10'

- **Floor**
  - Area: 100 sq ft
  - Dimensions: 10' x 10' x 10'

- **Roof**
  - Area: 125 sq ft
  - Dimensions: 10' x 10' x 10'

These three parts together form the Whole Building.
DATABASE
ABOUT

At the beginning of each set of assemblies (per project) is a graph comparing all of the assemblies for that specific project and the outputs for each impact category. This gives a quick reading of which assemblies are performing better than others. However, an assembly may do well in one category and poorly in another; this is where narrowing the scope of the inquiry becomes important.

The database contains various layers of information, but is intended to be a simple preliminary glance at the environmental impacts of an assembly. This database can be reviewed at the onset of a project when preliminary decisions on materials and structural systems are being made. The potential wall in question can be looked at through the lens of the impacts of different material choices. One can quickly spot problem areas (typically insulation), and choose to focus on that part of the assembly in moving forward. In addition, the template is set up in such a manner that as future projects are developed, the new assemblies can be put into the database for future use - resulting in an ever-expanding set of information.

INFORMATION
The information contained within the template is a combination of Tally outputs and MSR office hierarchy. At the top there is an assembly section, whether it be a wall, roof, or floor, this can be easily pulled from DD or CD sets depending on where the project is in development. Below that is an R-Value of the assembly, if applicable. This can be an interesting piece to watch. The R-value can be tracked in relation to the impacts associated with the wall. In certain cases a lower R-value assembly will have larger impacts than a higher R-value assembly. Below this to the left are pie charts representing the Primary Energy Demand or Embodied Energy, and the Global Warming Potential, which is categorized by material. This is in relation to the 10ft x 15ft wall that was modelled in Revit, and is in relation to one another, adding up to 100%. This is a piece that can be looked at to isolate problem areas or materials (typically insulation).

To the right of the pie charts are the numbers for the Global Warming Potential and Primary Energy Demand for that specific assembly. The numbers are displayed as a total, as well as by the square foot.
To the right is an example of the template constructed, with labels indicating the various pieces of information contained within it. While this does not represent the full extent of all of the environmental impacts, it is designed to quickly and easily relay information about a specific assembly. The impacts displayed were edited down to Global Warming Potential (GWP) and Embodied Energy (Primary Energy Demand); this decision was made in relation to MSR’s hierarchy or priority list pertaining to the environmental impacts of materials. Narrowing down the scope is effective, as it filters the information, resulting in a less intimidating or overwhelming set of information to be interpreted.

The template and resulting database is not meant to stand alone, but rather serve as a reference guide. Assemblies can be compared and contrasted quickly; areas or materials of concern can be identified and monitored or tested further. Essentially, the template captures a snippet of the total environmental impacts.

DATABASE FORMAT
There are a series of database files grouped in different ways. They are as follows:

- Itasca Whole Building Analysis
  - Walls
  - Floors
  - Roofs

- Aeon Whole Building Analysis
  - Walls
  - Floors
  - Roofs

- Wall Type Database
- Floor Type Database
- Roof Type Database
ANALYSIS
WHOLE BUILDING

As stated previously, the databases are set up in different tiers or categories--by building project and by type. For the sake of this document, a portion of the information is presented. It is organized by whole building analysis comparing Aeon and Itasca, then goes into a few examples from each project of the wall, floor, and roof systems. The full database sets can be found in a separate document.

COMPARISON
The whole building analysis of Aeon and Itasca is compared in following pages. The information was filtered to examine the Embodied Energy, or Primary Energy Demand, Global Warming Potential, and Operational Energy or EUI.

While these projects are of different type and scale, comparing them begins to set up a relationship between outputs.
Below is an overall breakdown of the energy use, global warming potential, and size of each of the projects. While the projects vary in size and type, comparing the size and output numbers of each begins to draw up interesting questions.

Below are the total output numbers for both Itasca and Aeon. It is clear that Aeon is not only a significantly larger project as far as size is concerned, but obviously, with that greater size comes significantly higher output numbers. The total Embodied Energy of Aeon is roughly 44.8 million MJ’s compared to Itasca’s 7.2 million MJ.

Also seen below is the Operating Energy of each of the projects, and again, Aeon requires more energy to operate. The Operating Energy and Embodied Energy are compared both within each project and to one another.

The number of years it takes for the Operating Energy to catch up to the Embodied Energy in each project was calculated. While this is still a rough way of examining the relationship between Embodied Energy and Operational Energy, it generates useful questions.
ANALYSIS
WHOLE BUILDING

Below is an overall breakdown of the energy use, global warming potential, and size of each of the projects.

In order to begin drawing a direct comparison, the outputs for each project were broken down into output per square foot. This way the numbers could be looked at in more of a true comparative way. However, due to the vast square footage difference between the projects, a true comparison was unable to be made.

Aeon has significantly higher output numbers, coming in at 44 million kBTU of Embodied Energy, where Itasca only has 7 million. However, due to larger size of Aeon, the output per square foot of Aeon is less than that of Itasca.
ANALYSIS
EMBODIED ENERGY + OPERATING ENERGY

The following page contains a breakdown of the impacts per square foot, as well as a graph visualizing the number of years required for the Operational Energy to catch up to the Embodied Energy.

On the first day of a building’s occupation 100% of its energy use is Embodied within the building products and materials. Over time, energy is exhausted through Operational Energy, and eventually, this energy use will catch up and become equal to the Embodied Energy of a building. As buildings become more efficient, with lower Operating Energy, the Embodied Energy of materials become more important. The greater the Embodied Energy and lower the Operating Energy, the longer it will take for the numbers to equal out.

Aeon, with its significantly larger size, while possessing greater impacts, comes out looking to be in better shape than Itasca. Itasca, while its impacts are lower, also has a smaller footprint, resulting in higher impact per square foot numbers. While it has a high Embodied Energy (although not nearly as great as Aeon), it has a low Operating Energy of 17 kBTU/sq ft. However, this low Operating Energy and high Embodied Energy results in 37.7 years before the numbers will equal out.

In the case of Aeon, the Embodied Energy is roughly 47 million MJ, but with its higher Operating Energy, it only takes 9.8 years for the numbers to equal out.

BASELINE ISSUES
As stated previously, these comparisons are rough in that they exist within a bubble. To date, there are no standards for building products and materials, or no average. In addition, the establishment of a baseline building is also lacking. Without a definitive baseline to compare these numbers to, they are relative to one another. However, that does not mean they are irrelevant; they generate a plethora of questions that will propel this research forward within the profession.

The biggest question through this whole project has been focused around what the outputs mean. How is the office doing in the grand scheme of things? Are their energy efficient buildings performing efficiently in terms of environmental impact? Are they doing well, average, or poor? What is the target zone?
ANALYSIS
BASELINE + COMPARISON ISSUES

Unfortunately, to date, there exists no averages or targets for the environmental impacts of materials and building products. Architecture 2030 is developing a 2030 for Products framework, which will establish product category averages. Essentially, the averages will act as a benchmark to measure a project's impacts against. Similar to the initiatives energy goals, the target impact decreases in intervals over the years leading up to 2030.

In an attempt to begin developing some way to compare the impacts of Aeon and Itasca, the comparison was extended to a brief study of office buildings in Chicago and New York. The energy information pertaining to the Chicago and New York buildings came from the AIA 2030 Annual Report.

The Operating Energy, Embodied Energy, and time it takes for the numbers to meet was compared across the office projects and the MSR projects in question. Similar to other comparison attempts, it exists in a bubble, and raises more questions than it answers. However, it does outline a few relationships. If a project has a high Embodied Energy with a low Operating Energy, the number of years it takes for the numbers to meet will be greater than if the project has both a high Embodied Energy and high Operating Energy.

The relationship between Embodied Energy and Operating Energy can be seen here to the left. The two are inextricably linked; as one number changes, so does the other. In addition, the energy (embodied or operating) is also tied to the size of the project, the floor area to envelope ratio, and the expected lifespan of the building. In essence, it is a complicated relationship that has yet to be fully resolved.
The information on this page is merely an example of a different way of evaluating the outputs from a whole building analysis from Tally. The program outputs the information in various ways; depending on the line of inquiry, different output styles are more informative than others.

Below each project is a graph output from Tally. It contains each impact category with the total impact broken down by CSI division. This is just one of many different output styles available from Tally. This is what is so nice about the program -- the output can be chosen based on the line of inquiry, and which issues the designer is tracking.

The CSI graph below allow easy identification of problem areas, as does the output categorized by material entry. It is easy to see at first glance which categories are causing the greatest impact, providing focus for future analysis and study. It isolates which part of an assembly or building is resulting in the highest impacts, and provides a focused trajectory for designers wishing to reduce the environmental impacts of their designs.
ANALYSIS
DATABASE_WALL ASSEMBLIES

The next area of focus goes from examining the building in its entirety to focusing on the wall assemblies. All exterior wall types from each project were run through the same analysis, resulting in the database outputs.

Again, this test wall consisted of a 10’x15’ wall.
The following pages include portions of the database for both Aeon and Itasca. For the sake of keeping this document slightly smaller, the database(s) in their entirety can be found in a different document. There is a separate database for Wall Types, Floor Types, and Roof Types. In addition, a Full Building Analysis of both Aeon and Itasca, as well a comparison document can be found on the server.

Below is the Itasca wall type summary page. The summary page begins each portion or project within the Wall Type Database. The graph is an output from Tally, resulting from a Design Option Comparison Analysis. This type of analysis is helpful in that it allows the user to see the various wall assemblies in direct comparison to one another across the impact categories.

This demonstrates again how complex this analysis can get. One wall may be performing well in one category but poorly in another. This is why establishing a goal and scope at the onset of the study is valuable; it allows the user to focus or target a certain aspect rather than trying to juggle all of the variable at once.
ANALYSIS
DATABASE_WALL ASSEMBLY EXAMPLES

To the right are three of the five Itasca wall types. To view all of the walls analyzed see the Wall Type Database. The template developed allows for a quick comparison between wall types. The idea is that walls existing in the database can be reviewed early in the process of a new project, to aid in making early material and assembly details. Further information on the assemblies can be found in the full Tally outputs. As new wall types are developed they are added to the database.
ANALYSIS
ITASCA_ASSEMBLY CHANGE

The study to date was based off the Construction Document set for Itasca, however, like with many projects, the assembly changed along the way due to cost. The whole building analysis has been updated to reflect the recent changes to the wall assembly, however, the wall assembly database remains based off the original CD set. Wall 1 was adjusted to match the new assembly and the results were compared against one another. The changes were minor, but had a relatively high impact on the results. The overall Global Warming Potential went down in the new assembly, while the Embodied Energy went up, but also resulted in a lower R-value assembly.

ORIGINAL ASSEMBLY
- 5/8 Gypsum wall board
- 3-1/2” Mineral fiber blanket insulation
- 3-3/4” Closed cell polyurethane spray foam
- 1/2” Plywood sheathing
- Air barrier
- 2” Semi-rigid mineral fiberboard insulation
- 1” Semi-rigid mineral fiberboard insulation
- Hardie Lap Siding
- LVL framing

UPDATED ASSEMBLY
- 5/8 Gypsum wall board
- 3-1/2” Mineral fiber blanket insulation
- 2-1/2” Closed cell polyurethane spray foam
- 1/2” Plywood sheathing
- Air barrier
- 2-1/2” Extruded Polystyrene (XPS)
- 1” Semi-rigid mineral fiberboard insulation
- Hardie Lap Siding
- LVL framing
ANALYSIS
DATABASE_WALL ASSEMBLY SUMMARY

To the right is the Wall Assembly Summary for Aeon. Here, eight exterior wall types can be seen next to one another. On the top runs a small strip of wall sections, identifying the wall types that were analyzed. Again, as this is the summary graph, it is meant to be used for an overall look at the wall types in question. More in depth information relating to each wall can be found in the individual wall information slice following. Yet more information can be found in the full Tally results.
The Database and its assembly slices are essentially filters for the vast amount of information that Tally outputs. The summary is the first quick glance, the assembly slice reveals yet more information, allowing for more in depth comparison between assemblies, and the comprehensive report can be found in the full Tally output. As the users questions become more specific, different resources are consulted.
ANALYSIS
DATABASE_WALL ASSEMBLY EXAMPLES

To the right are three assembly slices of the total eight that were analyzed. Again, the user is provided with a quick overview of the wall type, its Global Warming Potential and Primary Energy Demand. This is broken down in the pie charts by CSI division so that different materials can be isolated in relation to the overall impact. It can be noted that while Wall AAA has a higher R-value that Wall 3A, its Global Warming Potential per square foot is significantly lower.
ANALYSIS DATABASE_FLOOR ASSEMBLIES

Following the analysis of the wall types contained within each of the two projects, the floor assemblies were investigated. As is demonstrated in the pie charts to the right, the floors account for 20-32% of the total impacts of the building. Due to this large percentage of impact, it is important to understand the assemblies, and isolate where potential changes could positively or negatively impact the environmental impacts.

Legend
- Roof Categories
  - Revit: Ceiling, Roof PANEL, Roof Rail, Mullions
  - System: Roof and Floor Envelope, Walls
- Material Types
  - Steel, Wood, Drywall, Glass, Metal, Plastic

Floor

Area: 100 sq ft
10' x 10'

Direct Comparison

Capabilities
- Whole building assessment
  - Accurate sq. footage + geometry
  - Easy option comparison
  - 3D model visualization
  - Design Option Comparison
- Assembly assessment
  - Design Option Comparison
  - Assemble wall type database
- Quick material/product comparison
  - Assess Impacts between options
  - Design Option Comparison

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ANALYSIS

DATABASE_FLOOR ASSEMBLY SUMMARY

Below is the Wall Assembly Summary for Aeon. Here, eight exterior wall types can be seen next to one another. On the top runs a small strip of wall sections, identifying the wall types that were analyzed. Again, as this is the summary graph, it is meant to be used for an overall look at the wall types in question. More in depth information relating to each wall can be found in the individual wall information slice following. Yet more information can be found in the full Tally results.

The Database and its assembly slices are essentially filters for the vast amount of information that Tally outputs. The summary is the first quick glance, the assembly slice reveals yet more information, allowing for more in depth comparison between assemblies, and the comprehensive report can be found in the full Tally output. As the users questions become more specific, different resources are consulted.
ANALYSIS
DATABASE_FLOOR ASSEMBLY EXAMPLES

The assembly slice for the Itasca floor can be seen below. While the floor has a low Global Warming Potential, the Primary Energy Demand is significantly larger by comparison. Also, the assembly only contains a few materials, but concrete and its associated reinforcing are responsible for the bulk of the environmental impacts.
ANALYSIS
DATABASE_FLOOR ASSEMBLY SUMMARY

Aeon, being a larger project, contained five different floor assemblies that were analyzed with Tally. Below is the summary of the five assemblies compared against one another. Here again it can be seen that one assembly may perform well in one impact category and poorly in another. Decisions should take into account multiple aspects, and balance the environmental impacts. The following page includes the database information for three of the five floor assemblies. The full analysis can be found in the Floor Database file.
ANALYSIS
DATABASE_FLOOR ASSEMBLY EXAMPLES

To the right are three of the five assembly slices for the Aeon project. It can quickly be seen that the assemblies containing concrete have a larger Global Warming Potential and Primary Energy Demand than the assembly that does not.
ANALYSIS
DATABASE_ROOF ASSEMBLIES

As can be seen in the pie charts below, the roof assemblies contained within the two projects account for 9-37% of the total environmental impacts. Again, due to this larger number, the roof assemblies were chosen for examination.

The pages following contain a few examples of the assembly slices from each project.
ANALYSIS
DATABASE_ROOF ASSEMBLY SUMMARY

Similar to what has been presented previously, the Itasca Roof Assembly Summary can be seen below. At first glance, it can be seen that Roof C is performing poorly in relation to the other roof types as far as Ozone Depletion Potential, but better than Roof A in Smog Formation Potential.

This is a way to quickly isolate assemblies and their potential problem areas in relation to the different impact categories.

The full analysis can be found in the Roof Database file.
Below are three roof assembly slices from the Itasca project. Here, the environmental impacts increase between each different roof type.
ANALYSIS
DATABASE_ROOF ASSEMBLY SUMMARY

Similar to what has been presented previously, the Itasca Roof Assembly Summary can be seen below. At first glance, it can be seen that Roof C is performing poorly in relation to the other roof types as far as Ozone Depletion Potential, but better than Roof A in Smog Formation Potential.

This is a way to quickly isolate assemblies and their potential problem areas in relation to the different impact categories. The full analysis can be found in the Roof Database file.

AEON

ROOF 1

MEMBRANE

Legend

Design Options

AEON ROOF 1 (primary)
 Below is the roof assembly slice for Aeon. As was found in other sets of assembly slices, the Thermal and Moisture Protection materials are responsible for the bulk of the environmental impacts. In most cases this is linked to insulation. While responsible for the largest portion of environmental impacts, insulation is extremely valuable in its ability to increase a building's operational efficiency. This again shows the complex relationship between operational energy and embodied energy. While insulation will drive up the embodied energy of a building, it will lower the operational energy. Here is where decisions and compromises must be made on a project by project basis.
ANALYSIS
DATABASE_INDIVIDUAL MATERIALS

The power of Tally extends beyond full building or assembly analysis and into that of individual materials. The following pages include results from two different studies. The two studies focused on different insulation and cladding. The assembly remained constant, with the individual materials swapping out and being analyzed in relation to one another. This is an extremely powerful option in the design process. When deciding on which cladding, insulation, structure, etc to use, a quick study can show the environmental impacts of each different material choice.

In some cases, a certain material must be used, however, if a few options are available, this form of analysis reveals the impacts of each material, and thus the decision. This can be used to aid in determining which material or product is best for the project, client, or situation.
Below is the summary chart from the cladding study. Again, the rest of the assembly was consistent between the three, while the cladding material was altered. Similar to the summary charts seen previously, a certain wall, or in this case cladding, may perform well in one category but poorly in another. For instance, Terracotta is generally resulting in lower environmental impacts than the other two materials, however, in the case of Primary Energy Demand, it results in a greater impact.
Below are the three assembly slices for the cladding study. In this case, looking at the hard numbers versus just the summary graph is crucial. At first glance the summary graph makes the impacts look significantly different between the three materials, but in looking at the assembly slices, the environmental impacts are relatively close.
The study below focuses on different insulation types. Again, the rest of the assembly remained constant, while the insulation type was changed. At first glance, closed-cell spray foam appears to be resulting in the largest environmental impacts. However, it is highly efficient as an insulator; to reach the same R-value with a different insulation typically results in a much deeper wall assembly and more material. So in cases where a high R-value is desired while keeping a shallower wall, closed-cell spray foam may be the best option. Insulation tends to be the material responsible for the greatest impacts, but also serves to lower the operational energy of a building. This again demonstrates where clear priorities and goals should be established in running analysis and making decisions in respect to different projects.
ANALYSIS
DATABASE_INSULATION_TYPES

Below are the assembly slices for the different types of insulation. It can be seen that with the different insulations, the R-value decreases because the thickness remained constant between the different types.

WALL 1AAA
CLOSED CELL

TOTAL:
1,677.8
kgCO2eq

PER SQ FT:
11.2
kgCO2eq/sq ft

R-34

WALL 1AAA
FIBERGLASS BATT

TOTAL:
712.6
kgCO2eq

PER SQ FT:
4.8
kgCO2eq/sq ft

R-19

WALL 1AAA
CELLULOSE

TOTAL:
727.5
kgCO2eq

PER SQ FT:
4.85
kgCO2eq/sq ft

R-18.7

Legend
00 - Metals
01 - Steel, cold
06 - Wood/Plastics/Composites
08 - Wood/Plastics/Composites
12 - General insulation (Type 1)
16 - Wood framing
17 - Thermal and Moisture Protection
20 - Fiber cement siding
21 - Fiber cement siding
30 - Finishes
36 - Wallboard, gypsum

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CONCLUSION

While this research covers a lot of ground, it is but the beginning of something larger. The profession is still searching for benchmarks to compare environmental impacts and to help gauge how we are doing in relation to this. While murky at this point, as more research is done, solutions will become more clear. The most important part of this process is to bring the environmental impact of materials into the conversation. As the profession continues to investigate the impacts of the projects that are built, the knowledge base will grow. Similar to the advances we have been making in relation to the operational energy of buildings, as focus expands to include the embodied energy of materials, we can only get better.

OFFICE INTEGRATION
Discussions went on throughout this process on how to best relay information to the office and encourage conversations and use of this information and tool. The goal is to fold this into the design process of every project. While training an entire office in how to use a tool would be helpful, it would also be resource and time consuming. Therefore, the best way to ensure continued use and the dissemination of information is through a small group of ‘experts.’ Ideally, each project team will have someone versed in this knowledge and passionate about making a change. Through this, the conversations will expand and knowledge grow.
Introduction
Education of the Office

What will work?

Database:
- Reference guide
- Assemblies
- Materials

Tool Centered:
- Education on use of tools
- Integrate into process

Integration:
Options

Outside Consultant
Expert in house
Small Group
Whole Office

Expert
Expert
Expert
Expert
BIBLIOGRAPHY


