An Evaluation of Life Cycle Analysis (LCA) Tools for Environmental Impact Analysis of Building End-of-Life Cycle Operations

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ABSTRACT

Building life cycle assessment (LCA) is an important methodology associated with the sustainable construction. The LCA method enables the construction stakeholders to quantify and assess environmental impacts of construction activities, which ultimately helps them make more environmentally friendly decisions. Multiple LCA tools have been developed around the world in order to not only facilitate the application of the LCA method within the industry, but also incentivize architects, engineers, and contractors to apply this method within their decision making processes. Many of the existing LCA tools consider the life cycle of a building in five stages, namely manufacturing, construction, operation, maintenance, and end-of-life. However, these tools lack when it comes to environmental impacts analysis at building end-of-life cycle. This study aims to identify how much two well-known LCA tools (SimaPro and Athena IE), which are currently in use in the industry today, support the building end-of-lifecycle operations for making informed decisions. For this purpose, SimaPro and Athena IE are used to simulate the environmental impact assessment of a real world case study with different end-of-life scenarios. The results of this study highlight current deficiencies and benefits of these LCA tools along with a substantial need for a customized LCA-based tool which enables decision makers to make more environmentally friendly informed decisions at the building end-of-life cycle.

INTRODUCTION

The building sector is responsible for 160 million tons debris per year, accounting for nearly 26 percent of total non-industrial waste generation in the U.S. (EPA 2008). In 2003, 40 percent of construction and demolition waste (C&D) was recycled, reused, or recovered, while the remaining 60 percent was sent to C&D landfills (EPA 2008). Based on the available data from the same year, demolition activities resulted in nearly 53 percent of total C&D materials while nearly 38 percent of the waste comes from building renovation and retrofit. The waste that comes as an output of new construction activities and is targeted by Lean construction initiatives is only 9 percent of total C&D materials (EPA 2008; EPA 2009). There are various studies and government agency reports that indicate poor performance of the construction industry during end-of-life cycle operations (Wagner 2002; EPA 2010; DOE 2006).

Before taking any action for reducing environmental impacts of the construction industry, it is necessary to measure those impacts through quantitative methods, such as Life Cycle Assessment (LCA) method. There is an increasing awareness of LCA as a methodology for studying environmental impacts within the construction industry (Eaton and Amato 1998). The LCA method enables the decision and policy makers to quantify environmental impacts of a facility during its life cycle (Trusty 2000; Zhang et al. 2006). Many of the existing LCA tools consider life cycle of a building in five stages, namely *manufacturing, construction, operation, maintenance, and end-of-life.* However, in practice, there is less concern for the *end-of-life* stage while large volumes of effort have been directed towards environmental impact analysis at the *manufacturing, construction, operation* and *maintenance* stages.

LCA tools have different approaches for end-of-life of a building. In some tools, building end-of-life operations are mainly seen as a conventional demolition activity resulting tons of waste that is sent to landfills (e.g., Athena IE). These tools conduct LCA based on materials and energy used for the demolition of the whole building. On the other hand, tools such as SimaPro, gives the user the opportunity to choose different destinations for materials such as reuse or recycling facilities. However, in real world operations, conventional demolition is not the only option at the end-of-life cycle of a building. More sustainable alternatives such as deconstruction, as a process of dismantling a building for recycle and reuse, is being practiced by many contractors that not only alleviates the environmental impacts of the construction industry, but also provides jobs and training opportunities followed by economical benefits to a community (Guy and Gibeau 2003).

This study focuses on the end-of-life cycle of a building with its associated environmental impacts. The aim is to explore the potential applications of two recognized LCA tools for different end-of-life scenarios and identify deficiencies and potential improvements.

LCA-BASED DECISION SUPPORT TOOLS

Since measuring and quantifying environmental impacts of buildings is a complex task, several tools have been developed to simplify the LCA process. A study by Trusty (2000) analyzes the existing LCA-based tools based on their focus, intent, and use. For the purpose of this study, we consider two tools in order to conduct LCA of the deconstruction and demolition of a wall system. SimaPro and Athena Impact Estimator (IE) are the two tools selected due to their wide recognition in the industry and their coverage of the US data. Although SimaPro is designed for use in the Netherlands, it has a comprehensive database that also covers the North American data. Athena IE is specifically designed for the USA/Canada. *Athena Impact Estimator* is a life cycle environmental assessment tool that is applicable to new construction and existing buildings. Athena IE enables the user make a report of each life cycle stage of the building. For example, the user can have a transportation fuel consumption report of construction or energy needed to demolish a building. This tool aims to help building designers, product manufacturers, and policy makers to compare the relative environmental impacts across alternative solutions at the conceptual design stage. *SimaPro* is a professional tool to collect, to analyze, and to monitor the environmental impacts of building products. The reason of using SimaPro for evaluating environmental impacts of deconstruction is that this LCA tool enables the user define different scenarios for materials and products for the end of life. In addition, results can be presented for each individual assembly/subassembly, product or material. SimaPro considers five product stages for its LCA, namely assembly, life cycle, disposal, disassembly, and reuse. Furthermore, product stages are linked to processes which contain data on raw materials, emissions and outputs.

APPROACH

The research approach of this paper is based on a case study of real world end-of-life operations on external walls of an 80-year old university building.

We observed the demolition of the south wall and deconstruction of the east and the west walls with the aim of simulating these two scenarios in LCA tools. Athena IE is selected for simulating the demolition process of the south wall since this tool does not support deconstruction operations. SimoPro is used for the simulation of deconstruction of the east and the west walls. Both tools contained the required material inventory in their database and there was no need for using any external databases.

Environmental impact categories and methods are slightly different between SimaPro and Athena. However, the LCA concept remains the same as both tools are designed for simulating building life cycle and its associated environmental impacts. Athena IE reports environmental impact measures consistent with the US EPA TRACI methodology (EPA 2007). Furthermore, the environmental impacts in Athena IE, can be reported in two formats: "Summary Measures" and "Absolute Value". This study presents the "Summary Measures" including *Fossil Fuel Consumption, Global Warming Potential, Acidification Potential, Human Health (HH) Criteria, Eutrophication Potential, Ozone Depletion Potential, and Smog Potential.* Unlike Athena IE which has only one impact assessment method, SimaPro encompasses several impact assessment methods, namely BEES, Eco-indicator 95, Eco-indicator 99, EDIP/UMIP, EPS, Ecopoints 97, Impact 2002, etc. (PRé Consultants 2008). The basic structure of the impact assessment methods in SimaPro, include Characterization, Damage Assessment, Normalization, and Weighing (PRé Consultants 2008). However, for the ease of comparison with the Athena IE results, this study focuses on the analysis results calculated through Eco-indicator 99 method, and based on Characterization structure. Outputs of Eco-indicator 99 method covers environmental impacts including *Carcinogens, Respiratory Organics, Climate Change, Radiation, Ozone Layer, Ecotoxicity, Acidification/Eutrophication, Land Use, Minerals, and Fossil Fuels.*

Although the study focuses on simulating processes associated in demolition and deconstruction in LCA tools as accurately as possible, it does not define and measure the minor tasks for each process. For instance, the possibility of the use of a light equipment, such as a Bobcat during the disassembly is considered in LCA calculations, but the exact amount of fuel consumption of that equipment is not measured and reported.

CASE STUDY

In order to make an informed decision for a building's end-of-life cycle and its environmental impact, we need to conduct LCA to identify effects of each scenario on building's environmental footprint. Figure 1 shows the external wall section of the university building used in our case study. The material quantities of the wall are also presented in Table 1. Masses and volumes of the materials are calculated for the wall area of $1m^2$.

External wall at the south side of the building was completely demolished while walls at the east and west sides were disassembled for the purpose of reusing the cladding, which was built from Hokie Stone. Hokie Stone is a coined term referring to a grey dolomite limestone infused with magnesium and calcium under intense pressure and temperature. Hokie stone is the primary finishing material on Virginia Tech campus buildings. The main reason of dismantling and reusing the Hokie stone is retaining the best cosmetic match between the existing part of the building (north side) and the new construction.

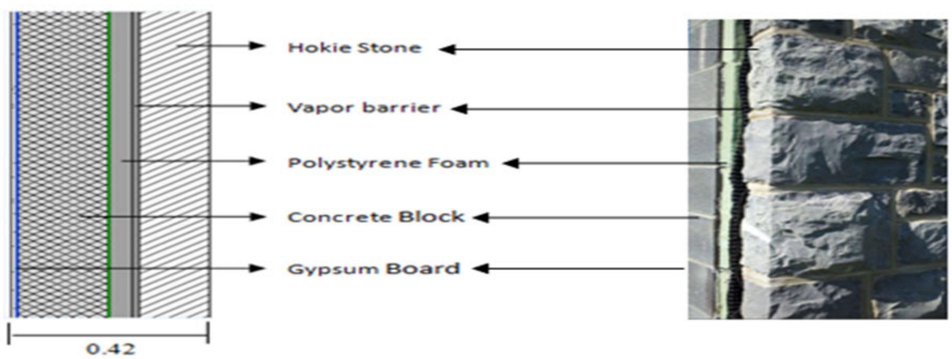

Figure 1. External Hokie Wall Section

Table 1. Materials of the External Wall

Material	**Density** kg/m^3	**Volume** m^3	**Mass** kg	**Layer Thickness** m
Hokie Stone	2483	0.15	373	0.15
Vapor Barrier	940	0.01	9.4	0.01
Polystyrene Foam	28.8	0.05	1.44	0.05
Concrete Block	3000	0.20	600	0.20
Gypsum Board	600	0.01	6	0.01

As the building was partially demolished and deconstructed, simulations were done in two scenarios. The first scenario simulates traditional demolition of the external Hokie stone wall at the south side of the building. The second scenario simulates the deconstruction of the walls at east and west sides for the purpose of reusing the Hokie stone and recycling the concrete block.

SCENARIO 1

The first scenario of wall demolition was simulated by Athena IE. The results are presented in "Summary Measures" format in Table 2. Although Athena IE is a LCA-based tool for whole building analysis, this study only simulates the external wall assembly. However, the result of the wall simulation is reliable since the whole building analysis is done on assembly level including foundations, walls, columns and beams, roofs, and floors.

Simulating the demolition of the wall in Athena IE, was a relatively easy task. Athena IE offers multiple wall cores together with different layer options. For instance, the wall section of this study includes a core of concrete block and additional layers of vapor barrier, polystyrene foam, and gypsum board.

Table 2. Summary Measure (End-of-Life)

Summary Measures	**End - Of - Life**		
	Material	**Transportation**	**Total**
Fossil Fuel Consumption (MJ)	1.45e+01	1.50e+01	2.95e+01
Global Warming Potential (kg CO2 eq)	9.74e-01	1.15e+00	2.13e+00
Acidification Potential (moles of H+ eq)	5.24e-02	3.54e-01	4.06e-01
HH Criteria (kg PM10 eq)	7.02e-04	4.60e-04	1.16e-03
Eutrophication Potential (kg N eq)	5.25e-05	3.34e-04	3.87e-04
Ozone Depletion Potential (kg CFC-11 eq)	4.26e-11	4.60e-11	8.85e-11
Smog Potential (kg O3 eq)	5.09e-03	1.88e-01	1.93e-01

Athena IE calculates the following for the end of life of the external wall with the demolition scenario:

- The materials and energy used to demolish whole external wall;
- The physical amount of materials of the external wall that is destined for landfill. Note that this amount is calculated based on a percent of the materials that is sent to landfill and the remaining materials are assumed to remain on site. (This uncertainty is due to lack of consensus within North America in the area of solid waste.)
- The materials and energy used to transport materials to landfill. As mentioned earlier, only a certain percentage of each material is designated to landfill and possible environmental impacts of the remaining materials, on the jobsite, are not considered in the simulation.

The end-of-life module in Athena IE simulates two items; (1) demolition energy and (2) final disposition of the materials incorporated in the 1m^2 of the external wall. The deficiency of this simulation is that Athena considers traditional demolition as the only end of life scenario and does not allow users to simulate different end of life scenario such as deconstruction. Furthermore, Athena does let the user define neither percentages of materials which are sent to landfills nor materials remaining on the jobsite for the purpose of reuse or recycling. The abovementioned deficiencies of Athena IE, would result in inaccurate environmental impact analysis of the building end-of-life cycle.

SCENARIO 2

In the second scenario, deconstruction of the east and west external walls is simulated in SimaPro. SimaPro offers a LCA wizard which helps the user to set up LCA models. This wizard is particularly designed for simulation of different end of life scenarios. The user can model end-of-life with a disposal approach or with a waste approach. A waste approach is defined on material level, while a disposal approach is for assembly/product level. In a disposal approach, the user can define what percentage of an assembly is reused, disassembled or ended up in the waste. An example of waste approach in our case study is that a certain percentage of concrete block is recycled while the remaining waste is landfilled.

The Hokie stone of the east and the west walls was deconstructed to be reused for the new construction. We observed that approximately 85 percent of the whole Hokie stone was reusable for the new construction, while the remaining 15 percent was considered debris and sent to landfill. Although in the case study, the concrete block was demolished completely and sent to landfill, this study considers the possibility of simulation of recycling concrete block for aggregate. It was assumed that 80 percent of the concrete block is recyclable and the remaining 20 percent would be sent to landfill. Other materials of the walls were demolished and sent to landfill. The method used for this LCA was Eco-indicator 99. Figure 2 represents simulation results generated by SimaPro.

As Figure 2 indicates, the user is able to extract LCA characterization for each material of the wall assembly at the end of life cycle. Whereas, Athena IE does not allow the user to acquire environmental impacts of individual product/material. This feature of SimaPro is especially important when a contractor wants to decide the most proper environmentally destination for each material. For instance, if the gypsum board recycling plant is far away from the project site, by considering the transportation energy consumption and recycling process, sending the gypsum board to the landfill may be more environmentally friendly approach. This decision can be made by simulating both recycling and sending to landfill approaches in SimaPro. However, since this comparison is not in the scope of this study, no results and demonstration of such comparison are presented.

Figure 2 shows environmental impact contribution of each product/material. The data have been normalized and weighed according to Eco-Indicator 99 method using Egalitarian perspective. Since the aim of this study is only to evaluate the possible application of LCA tools at the end of life, no processes such as equipment needed for deconstruction was considered in the simulation. However, there is possibility to add different processes and transportation to the life cycle.

In addition to what mentioned earlier, in SimaPro the user is able to:

- Select multiple waste approaches in a disposal approach.
- Enter (in a disassembly) what percentage of that disassembly goes to its disposal approach.

While SimaPro has a very wide database from different sources and allows users to define different scenarios at the end of building's life, the results cannot be extracted by different life stages as Athena does. This means that LCA is carried out from the manufacturing stage to the end-of-life stage and presented as a single score. Although this can give valuable information regarding environmental impacts from "cradle-to-grave" approach in a case of traditional demolition, or "cradle-to-cradle" approach in case of deconstruction and reusing, the results do not reflect building's environmental footprint specifically at the end of life stage. This deficiency would be challenging specifically if the contractor wants to compare different end of life scenarios at the end of building life cycle.

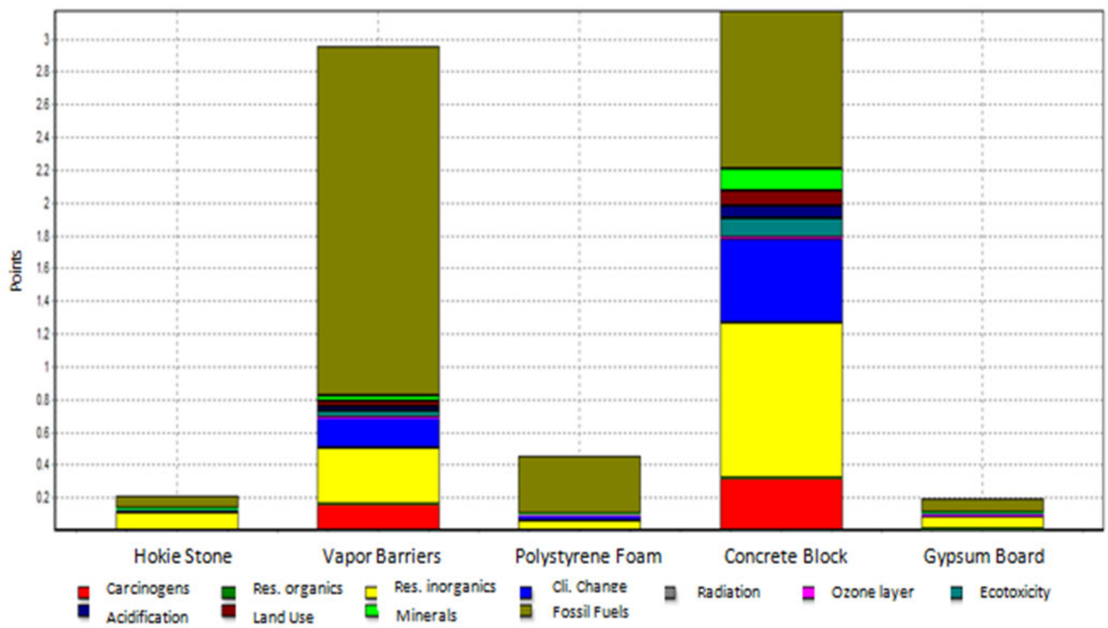

Figure 2. Single-score life cycle inventory assessment of the south and west external wall

CONCLUSION

Environmental impacts analysis of an external wall was presented to depict the applications of two LCA tools at the building end-of-life operations. Although analyzing different end-of-life scenarios for one wall assembly may not represent the whole building, it can highlight the possible applications, deficiencies, and potential improvements for the LCA tools at end-of-life of a building. By considering the deficiencies and potential improvements of the LCA-based tools, this study concludes that there is a substantial need for an easy to use and customized LCA tool for simulating building end-of-life operations. This tool can be used by the decision and policy makers to select the most sustainable scenario for each building element at the building end-of-life cycle.

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