INTEGRATING BUILDING INFORMATION MODELING AND LIFE CYCLE ASSESSMENT TOOLS TO DESIGN SUSTAINABLE BUILDINGS

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ABSTRACT

When it comes to the Architecture/Engineering/Construction (AEC) industry related software, one area of potential development that appears very promising is the integration of Life-cycle Assessment (LCA) tools with Building Information Modeling (BIM) models. However, performing an LCA on whole buildings is an exhaustive task due to the manual and repetitive nature of extracting building parameters from BIM models and inputting them into LCA tools. Moreover, the inaccessibility and complexity of LCA tools is another reason why such exercise is avoided by building professionals. In this paper, the literature regarding LCA, BIM, and data exchange standards that could facilitate integrating them is reviewed. A prototype is developed and validated where a level 2 LCA tool (Athena EcoCalculator) is linked to a BIM model (Autodesk Revit) to perform an LCA on a simple 3D object-oriented model using Industry Foundation Classes (IFC) as the data exchange standard.

Keywords: BIM, Building Information Modeling, IFC, LCA, Life-cycle Assessment

1. INTRODUCTION

It has become evident that the cumulative practices of the building industry over the years have had a significant negative impact on the surrounding environment. Actually, the building sector (residential and commercial) is the single largest contributor to global warming in the U.S. (U.S. Energy Information Administration, 2009). Similarly, a report published by the Commission for Environmental Cooperation in North America (Commission for Environmental Cooperation, 2008) states that buildings in Canada are responsible for:

"33 percent of all energy used;
50 percent of natural resources consumed;
12 percent of non-industrial water used;
25 percent of landfill waste generated; and,
10 percent of airborne particulates produced" (CaGBC, 2012).

In addition, energy used by buildings in North America produces more than 2,200 megatons of CO_2 released into the atmosphere, which accounts for 35 percent of the continents total (Commission for Environmental Cooperation, 2008). The Ontario Medical Association estimates that approximately 9,500 premature deaths per year are associated with exposure to air pollution in the province of Ontario, Canada alone (Ontario Medical Association, 2008).

In an effort to limit and counteract these effects, legislators together with environmental and building industry experts have been promoting the use of green methods and materials in the construction of new buildings under the label ‘green buildings’. The positive effects of green buildings is well-documented and according to the USGBC it can (on average) result in reducing energy consumption by 30 percent, carbon emissions by 35 percent, water use by 30 to 50 percent, and waste costs by 50 to 90 percent. (Commission for Environmental Cooperation, 2008).

However, if the current trends continue, the energy consumption is projected to increase by 28 percent in the residential sector and 39 percent in the commercial sector by 2030 (Commission for Environmental Cooperation, 2008). Therefore, there is an urgent need to inform building owners and the AEC industry of the benefits of green buildings and encourage the use of green practices in new construction and retrofit projects.

Consequently, the development of quantitative tools to demonstrate not only the environmental advantages, but also the economic gains that could be achieved by green buildings is essential. To that effect, Life Cycle Assessment (LCA) is a powerful tool that helps in communicating such benefits to stakeholders enabling them to have a better control and understanding of the different alternatives and outcomes involved.

2. METHODOLOGY

2.1 Literature Review

2.1.1 What are LCA, LCI, LCIA, and LCC?

LCA is an iterative procedure incorporating various steps in order to calculate the environmental impact of a product or service over its whole life-time (cradle to grave). The steps involved are: goal and scope definition, inventory analysis, impact assessment, and interpretation.

Life cycle inventory (LCI) is the data collection required to perform LCA. All inputs and outputs regarding the system analyzed are accounted for such as raw resources, energy, water, and emissions into air, water, and land. Performing such analysis is very complex and requires the investigation of numerous processes such as the transportation, extraction, manufacturing, use, and disposal of various resources.

Life cycle impact assessment (LCIA) is the step in which the global effects of items in the LCI are investigated. For example, the LCI will contain data on the flows in and out of the process of generating energy using fossil fuels such as CO_2. Subsequently, LCIA will quantify the impact of such flows on the environment. Finally, LCC is another cradle-to-grave approach that analyzes the direct monetary costs of a certain product or service (Athena Sustainable Materials Institute, 2012).

2.1.2 Comparison of LCA to Traditional Analysis

Many building owners consider green buildings as an unnecessary and costly trend marketed by environmental extremists (Frej, 2003). This is manifested in memberships of the Canadian Green Building Council (CaGBC), where 75% of its members are professional firms compared to a 2% of financers (Morrison Hershfield, 2005). Building stakeholders are typically required to meet capital cost budgets due to the structure of the bidding process typical of the construction industry. Any approach other than reducing direct costs is considered fiscally irresponsible due to the typical corporate structure that separates direct and operating costs. As a result, little emphasis is directed towards building performance during its life-cycle; and therefore, towards reducing the environmental impact.

The inclusion of LCA into the decision-making process will help support claims that green buildings are beneficial both from an environmental and economic perspectives; hence, encouraging building stakeholders to invest in them. For example, Romm (Romm, 1994) states that the initial building costs are about 2% of the total costs over a period of 30 years, compared to 6% maintenance costs and 92% personnel costs. Therefore, a 33% reduction in maintenance costs or a mere 3% reduction in personnel costs or an equal increase in workers’ productivity could offset the entire initial cost of the building.

As stated previously, a 30% reduction in energy costs is not unusual in green buildings. Furthermore, a study by Heschong Mahone Group (Heschong Mahone Group Inc, 2003) found that workers' productivity increased 13% due to higher daylight illumination levels, glare from windows decreased performance by 15% to 21%, better ventilation increased performance by 4% to 17%, and a 20% improvement in performance due to better physical comfort conditions. Another study by the same group (Heschong Mahone Group Inc, 1999) indicated that sales were up by 40% in a survey over an 18 month period on a sample of 108 commercial buildings that utilized day-light via skylights.

Such favorable conditions are typical in green buildings; hence, the use of LCA results early into the planning stage would definitely be in favor of more environmentally friendly construction because it will highlight higher operational cost savings/gains in comparison to initial costs. Incorporating LCA early requires its integration into the planning and design phases to capitalize on the environmental benefits of proper site selection and early coordination of different building systems (7group & Reed, 2009). An example of the later is the effect of architectural choices such as paint colors on the number and output of lighting fixtures, an item in the electrical system. Paint colors with high reflectance values (lower light loss factors) require less energy and lighting fixtures to produce the same illuminance (7group & Reed, 2009). Such coordination tasks have been significantly simplified with the introduction of Building Information Modeling (BIM).

2.1.3 Building Information Modeling and LCA

Adopting BIM greatly enhances the modeling and predictability of building performance. According to a Stanford University Centre for Integrated Facility Engineering study (CRC, 2007) based on 32 major projects, BIM benefits were: a 40 percent elimination of unbudgeted changes, cost estimation accuracy within three percent, an 80 percent reduction in time taken to prepare cost estimates, 10 percent savings of contract value due to clash detections, seven percent reduction in project durations, and a return-on-investment of 5 to 10 times for investing in BIM. Hence, incorporating LCA into the existing BIM framework is essential in order to push its utilization within the AEC industry.

According to Ortiz et al. (Ortiz, Francesc, & Sonnemann, 2009) building decision support tools during the operation phase of buildings are typically separated into two categories focusing on: building material and components combination (BMCC) and whole process of construction (WPC). BMCC is not as comprehensive as WPC because it is material-oriented. This causes it to focus on individual building components and their impacts rather than the net impact of the building's operation phase. For example, reducing the amount of insulation in the building might appear to produce greener buildings because of the environmental impact of manufacturing and installing it. Nevertheless, a WPC analysis will capture the energy savings caused by adding more insulation, which might end up offsetting the negative environmental impact of the added insulation. WPC prevents the sub-optimization of individual building components at the expense of the whole system.

According to Trusty and Horst (Trusty & Horst, 2005), LCA tools can be divided into three levels. Level 1 tools are BMCC tools that focus on individual products or simple assemblies. These tools are used to compare products against environmental and/or economic criteria, mainly at the specification stage of project delivery. Level 1 tools can be further sub-divided into two categories: Level 1A intended to be used by LCA experts and Level 1B for users who only want the results, such as conventional architects and consultants.

Level 2 tools are WPC tools that take into consideration complete building assemblies or elements. Typically, these tools focus on one area of interest such as operating energy, lighting, LCC, and life-cycle environmental effects. Level 2 tools are generally applied throughout the design process (early conceptual design to detailed design stages) and are more data-oriented and objective.

Finally, Level 3 tools are more comprehensive assessment frameworks that incorporate a wide range of environmental, economic, and social aspects of sustainability. They utilize a mix of objective (typically acquired using Level 2 tools) and subjective inputs (such as rating systems and criteria). Table 1 below lists examples of each level of tools adopted from various sources (Trusty & Horst, 2005; Kulahcioglu, Dang, & Toklu, 2012; GreenDeltaTC, 2012; Norris & Yost, 2002; Energy Plus, 2012; Autodesk, 2012; Integrated Environmental Solutions, 2012; USGBC, 2010).

Table 1: A Summary of Existing LCA Tools

LCA Tool	Country	Comments
Level 1A Tools - Product Comparison Tools for LCA Practitioners		
SimaPro	Netherlands	These tools can be used in different regions, but are LCA practitioner oriented.
GaBi	Germany	
Umberto	Germany	
TEAM	France	
Level 1B Tools - Product Comparison Tools for Non-LCA Practitioners		
LCE	USA	Prototype LCA Software to be Used by Decision Makers while addressing issues of context specificity, data uncertainties, and dominance of the usage phase.
OpenLCA	Germany	A modular software for life cycle analysis and sustainability assessments with a format converter (XML) and an uncertainty module.
BEES	USA	Combines LCA and LCC. Includes both brand-specific and generic data.
LCAiT	Sweden	LCA tool for product designers and manufacturers.
TAKE-LCA	Finland	LCA tool for comparison of HVAC products, including energy content and consumptions.
Level 2 Tools - WPC Tools		
Athena Environmental Impact Estimator (EIE)	Canada/USA	These tools use data and incorporate building systems that are specific to the country or regions for which they were designed.
BRI LCA (energy and CO2)	Japan	
EcoQuantum	Netherlands	
Envest	United Kingdom	
Green Guide to Specifications	United Kingdom	LCADesign is a promising tool that uses IFC to communicate with BIM software, but environmental data is currently limited to Australia.
LISA	Australia	
LCADesign	Australia	
VE-Ware	United Kingdom	
Energy Plus	USA	Energy simulation tools that are not based on LCA but significantly aid in the LCA of buildings.
Autodesk EcoTect & Green Building Studio	USA/Multinational	
Level 3 Tools - Comprehensive Assessment and Rating Frameworks		
BREEAM	United Kingdom	Uses LCA results from the Level 2 Green Guide.
GBTool	Multinational	Experimental platform that accepts LCA results or performs LCA calculations using built-in calculators.
Green Globes	Canada/USA	Assigns a high percentage of resource use credits based on evidence that a design team has conducted LCA using recognized Level 1 or 2 tools.
LEED	Canada/USA	Not LCA based but efforts have been put to incorporate LCA into pilot materials and resources credits.

3. DEVELOPMENT

Performing an LCA requires data acquisition of LCI for materials and processes utilized in the manufacturing and the construction stages of various building products. Then, this information is inputted manually into an LCA model. This routine of manually re-entering data into multiple software applications is tedious and effort consuming; hence, it is not completed by most AEC professionals (Fischer, M. et. al, 2004). These observations promote the integration of BIM software with LCA software to automate the process since material specifications and quantity take-offs are already included in BIM software (Russel-Smith & Lepech, 2012).

Potential development of future AEC/FM software is identified by Ma and Zhao (Ma & Zhao, 2008) to be in three areas: LCA of energy and environmental impacts, BIM support, and a file format that facilitates interoperability. Another paper (Loh, Dawood, & Dean, 2007) listed the deficiencies in the current LCA/BIM integration process as: the lack of interoperability between BIM and LCA tools, and the inaccessibility and complexity of LCA tools. Two solutions are proposed by Fischer (Fischer, M. et. al, 2004): improving the exchange of data between different programs or adding a built-in functionality into the BIM software to address LCA. Both options are investigated in section 3.1 of this paper.

To address the issues above, this paper presents an attempt to develop a simple integrative prototype between a Level 2 tool and BIM software. The Athena Environmental Impact Estimator offers environmental data specific to Canada and the USA easily accessible through the Athena EcoCalculator Excel spreadsheet auxiliary to the estimator (Athena Sustainable Material Institute, 2012). The EcoCalculator enables planners and decision makers to analyze the life-cycle environmental impact of buildings and their components in eight different categories: energy consumption, material resource use, global warming potential, acidification potential, human health respiratory effect potential, aquatic eutrophication potential, ozone depletion potential, and smog potential.

The EcoCalculator was chosen because of the wide-spread and understanding of Microsoft Excel by AEC professionals enabling them to reduce learning and development costs, especially for a tool that will be used mainly in the early planning stages. As for the BIM software, Autodesk Revit was chosen due to its popularity among designers in the Canadian AEC industry.

Revit is an object-oriented 3D modelling tool with the ability to perform material take-offs and export data in various formats, such as XML's and IFC. Consequently, the choice between different data exchange standards becomes the focus of this procedure and is discussed in the next section.

3.1 AEC/FM Industry Data Exchange Standards and Tools

Various data standards have been utilized for the exchange of information between multiple applications in the AEC/FM industry. Examples of data exchange standards include: CIS/2, gbXML, bcXML, IFCXML, OBIX, AEX, agcXML, BPC, IFD, IFC, and NBIMS (Karimi & Akinci, 2010). From the aforementioned standards, Revit enables model data export in two formats: gbXML and IFC.

3.1.1 Green Building Extensible Markup Language (gbXML)

gbXML is a data exchange standard developed by Green Building Studio with the support of the California Energy Commission's Public Interest Energy Research (PIER) Program, and the California Utilities Companies since 2000. It is specific to exporting data used by energy simulation tools. Building information for space, surfaces and zones, surface types, space area and air volumes, building type, building geographic coordinates, and information for light fixture elements can be represented by gbXML; however, its scope is limited to energy simulation and many parameters such as material U-values, space occupancy schedule, and global building coordinates generated from building simulation tools cannot be imported back to original applications with the added information (Karimi & Akinci, 2010).

3.1.2 Industry Foundation Classes (IFC)

Contrary to domain-specific gbXML, IFC currently has the widest scope out of all data exchange standards concerned with interoperability between AEC software. Developed since 1996 by buildingSMART, IFC facilitates the exchange of object information such as geometric representations and properties, topology, relations between components and spaces, special structures, costs, schedules, resources, documents, and many other parameters (Karimi & Akinci, 2010).

Due to its versatility, it is promoted as the future of interoperability by buildingSMART, academic experts, and AEC professionals. Nevertheless, deficiencies exist in establishing consistent semantics amongst different software vendors (Halfawy & Froese, 2005). Various software vendors define objects differently based on the context in their programs (East, 2012) and since IFC is developed by the non-profit buildingSMART, keeping up with the rapidly changing BIM industry is a difficult challenge. Yet, a fundamentally different option exists that is considered to be more practical by some BIM professional, at least temporarily until IFC can fully capture BIM models' data, which is vendor specific application programing interfaces (API).

3.1.3 Application Programming Interfaces (API)

Many BIM vendors realize the limitations of their software and enable users to customize them further using programming interfaces. Autodesk Revit for example, allows developers to extend the functionality or automate repetitive tasks using Revit API, which can be manipulated using any .NET compliant language. This corresponds to the second alternative proposed by (Fischer, M. et. al, 2004) above. Drawbacks of such proprietary solutions is that the model remains linked to a specific BIM vendor which limits the extraction of information from the model in the future if support to that specific software was not available. Therefore, IFC seems to be the preferred choice for data transfer and will be used in this prototype.

4. VERIFICATION

4.1 Prototype of BIM to LCA Tool Using IFC's

A simple Revit model of a wall (2600mm x 4000mm) and a door (915mm x 2134mm) were modeled. Using the type properties menu, "ATHENAD01" tag which corresponds to sheet D (exterior walls) and item 01 (brick cladding on concrete block) in the EcoCalculator spreadsheet was inputted in the (Type Comments) row for the wall element (Figure 1). The model is exported as a .IFC file which could be read using any text reading application (Figure 2). Using the IFC File Analyzer developed by NIST (NIST, 2012), the IFC file is exported into Microsoft Excel. A macro was then developed to search for the (Athena tag) in the (Type Comments) row, read the corresponding area or volume (Figure 3), read the system of units used (Figure 4), convert the area to square footage, and input it into the appropriate EcoCalculator spreadsheet cell (Figure 5). The LCA results can then be readily obtained. The process is outlined in (Figure 6).

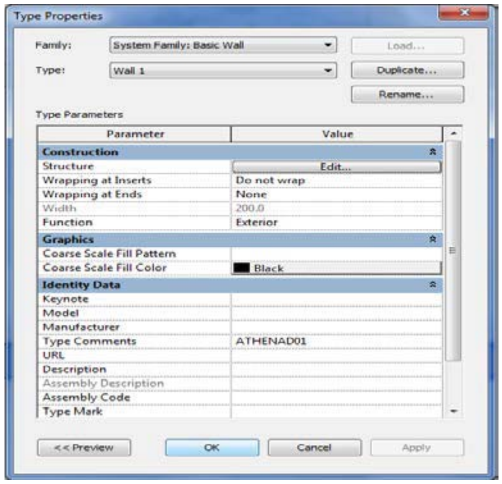


Figure 1: Wall's Type Properties Menu

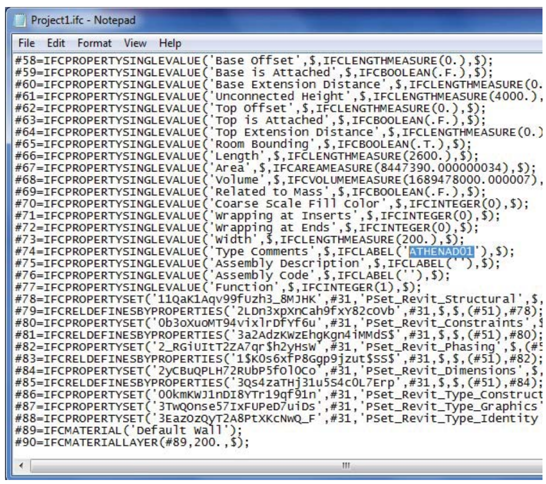
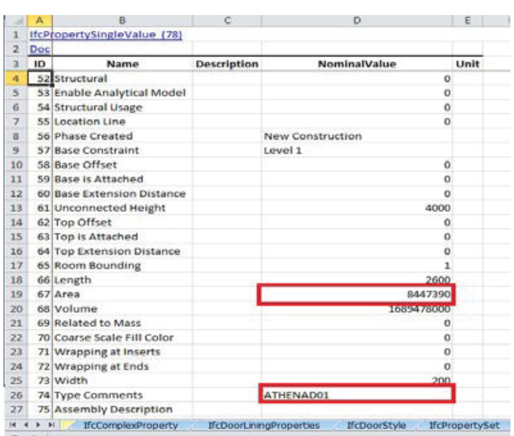
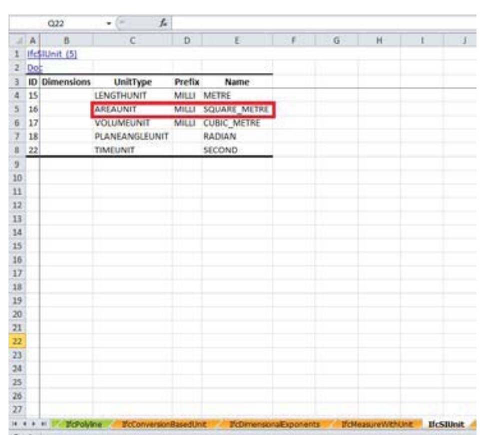


Figure 2: IFC File opened in Notepad

In Revit





Figures 3 & 4: Screenshots of the IFC File Analyzer Output File

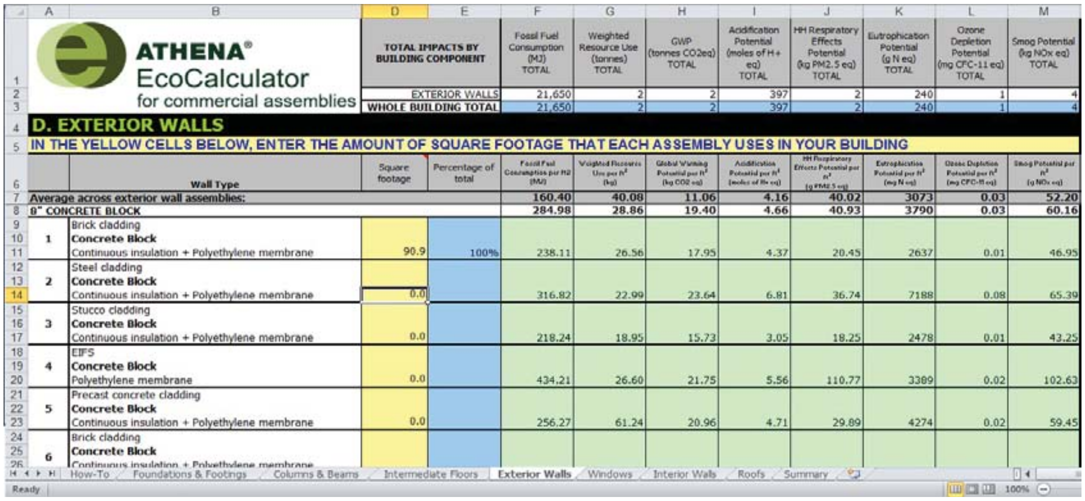


Figure 5: Athena EcoCalculator Input Screenshot for Commercial Assemblies in Ottawa

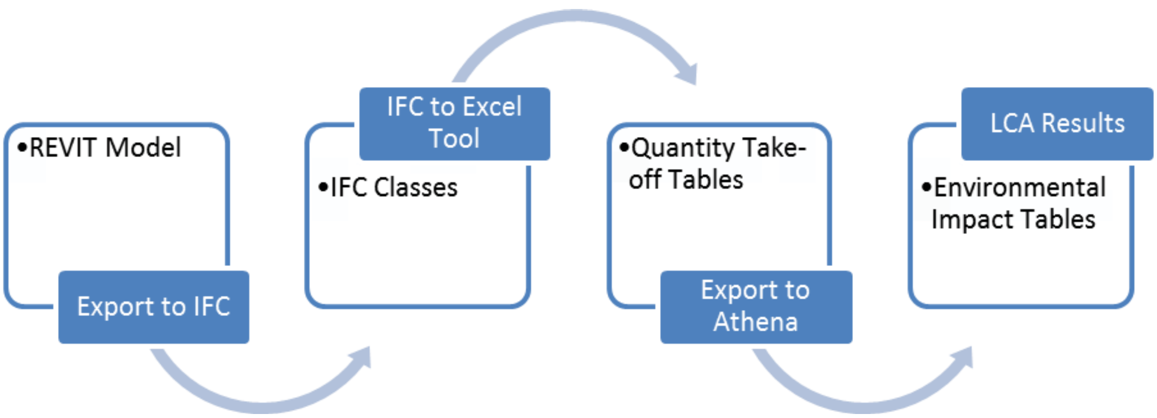


Figure 6: Flow Chart of the Integrative Process between Revit and Athena EcoCalculator

5. CONCLUSION AND FUTURE WORK

The integration of LCA tools with BIM models is performed using IFC as the data exchange standard. The BIM model had to be customized to label different BIM objects with their corresponding LCA tool item. The LCA was performed with ease and the process could be repeated by most building professional due to the lack of complex programing routines or the need to learn how to use new LCA tools as the whole process required proficiency in using the BIM software and Microsoft Excel only.

Future developments can prompt the user to select the appropriate EcoCalculator for the building type and geographical location in addition to customizing the user interface to allow for product comparisons. API's can be built into the BIM environment to make the LCA output more interactive and user-friendly.

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