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Whole-Building LCA and Green Building Rating Systems: Exploratory Review of the Available Tools

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Abstract. There is a growing interest in integrating Life Cycle Assessment (LCA) into building design decision-making, due to LCA's comprehensive, systemic approach to environmental evaluation. Many green building rating systems use LCA to various degrees. In this paper, we have performed a comparative study to evaluate the tools available to designers at different design stages and the means to meet the various green building rating systems requirements. The evaluation covers three different LCA software tools available to building designers: Kieran Timberlake's Tally, Athena Impact Estimator for Buildings, and SimaPro. The software tools vary in key aspects such as intended users (e.g., LCA experts or novices), design stage where they can be used, and time. The evaluated LCA tools also varied significantly in the possibility of their use in early design, decision-making, and integration with Building Information Modeling (BIM). Some of the applications rely on a bill of materials that change constantly in design alterations. A whole-building LCA of a large building using Kieran Timberlake's Tally was completed with future work including completing LCAs using Athena and SimaPro. The case study was highly influenced by the building type (i.e., healthcare facility) and its intense operational energy requirements. Conventional energy efficiency measures like increasing the lighting efficiency exceeded by far what can be done to mitigate the embedded impact of construction materials. We discuss in this ongoing research recommendations to advance the requirements of the baseline building and addressing the operational phase in more comprehensive framework.

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Introduction. Buildings provide countless benefits to society; nonetheless, they have substantial environmental and human health impacts. The building sector is the largest energy consumer in the US and worldwide (US EIA 2012). Civil works and building construction consumes 60% of the global raw materials extracted from the lithosphere; buildings accounted for 40% out of that. In Europe, the mineral extractions per capita intended for building accumulate up to 4.8 tons per inhabitant per year, which is 64 times the average weight of a person (Zabalza Bribián, Valero Capilla et al. 2011).

The architecture, engineering, and construction (AEC) industry is often acknowledged as a lowtechnology and an inefficient industry (Gallaher, O'Connor et al. 2004). Nonetheless this industry is undergoing profound and rapid transformations. Illustration of this transformation can be seen in the trend towards green buildings and sustainable development. 94% of AEC firms report some level of engagement in activities that are associated with green building. Those activities are often aimed at designing and construction green buildings to meet certifications. 28% of these professionals report high levels of green activity engagement, and more than 60% of their work is green or sustainable driven. These high levels of green building activity are expected to grow (McGraw-Hill Construction 2013).

There is growing interest in integrating Life-Cycle Assessment (LCA) into building design decision-making, due to LCA's comprehensive, systemic approach to environmental evaluation. There are many challenges that practitioners may encounter in the use of LCA, especially in the context of Green Building Rating Systems (GBRS). LCA may have beneficial contributions on several levels such as pre-design, schematic design, and design development stages of the design process. LCA can support architects and engineers in answering questions that arise throughout the design and construction process, and assist in their decisions based on scientific justifications. In this paper, we have performed a comparative study to evaluate the tools available to designers at different design stages and the means to meet the various green building rating systems requirements through the LCA lens.

LCA and Green Building Rating Systems. Since the early nineties, LCA was used as an assessment tool in the building's construction sector and has grown and expanded (Fava 2006).Today, there are many green building rating systems that use LCA to achieve environmental goals. Some rating systems and/or codes that have LCA provisions include: LEED by U.S. Green Building Council (USGBC 2013); BREEAM by U.K. Building Research Establishment (BRE 2014); IgCC by International Code Council (ICC 2012); Green Globes by Canada ECD Energy and Environment (GBI 2014); and CALGreen by California Building Standards Commission (CBSC 2013). Requirements vary from one to another and are likely to evolve in future versions.

For example, in LEED, the most prevalent and commonly used rating system, LCA was integrated as a pilot credit in 2009 for building assemblies and materials to encourage the use of environmentally preferable building materials and assemblies. LCA was not only used explicitly through the LCA credit but also implicitly incorporated into the current version of LEED, with likely expansion in the next versions, given the prominence of environmental product declarations (USGBC 2009; USGBC 2013). In the LCA credit, the design team has the option to perform whole-building life-cycle assessment and receive 3 points. The LCA should cover the project's structure and enclosure, and exclude energy consumption during the period of building's operation. The LCA results should *demonstrates a minimum of 10% reduction, compared with a baseline building, in at least two impact categories* (i.e. acidification of land and water sources; eutrophication, in kg nitrogen or kg phosphate; etc.) and global warming potential as a mandatory category (USGBC 2013). Comparison with a baseline building is prevailing practice in many green building rating systems and even some codes and standards. In LEED, the building achieves points in the water and energy categories by demonstrating reduction beyond a baseline building that was created based on a specified reference standard. For example, in the energy category, the baseline building must meet the ASHRAE 90.1 (Al-Ghamdi and Bilec 2015).

Today's Building Design and Construction Industry. Synergies and interconnectedness in the building design process represent an importance to whole building design. Today's practitioners work in more collaborative work environments. Whole building design relies on two components: an integrated design approach and an integrated team process. Today's technology supports practitioners and makes it easier to realize the integrated approach. Building Information Modeling (BIM) is seen as one such tool that can aid the building stakeholder community in accomplishing the design objectives. BIM is the system of production and management of a building's data during its life cycle (Lee, Sacks et al. 2006). Although BIM was available since the late 1980s, it did not evolve as a valuable tool for meeting sustainability objectives in the building sector until the green building revolution in 1990s. BIM extends to cover the different phases of the building design presses, where a massive amount of data is generated. BIM differs radically from the principle of Computer-Aided Design (CAD). BIM models, unlike CAD models, manage not just graphics, but also information. BIM has faced many legal and technical obstacles; despite BIM demonstrating benefits in the areas such as sustainable design, construction, facilities management and estimating (Becerik-Gerber and Kensek 2010).

Investigative Method. We have conducted a comparative analysis of three LCA building software tools: Athena Impact Estimator for Buildings, Kieran Timberlake's Tally and SimaPro. We completed a whole-building LCA using Tally for a large hospital in Pittsburgh, PA. The Tally LCA represents complete architectural, structural, and finish systems and was used to compare the relative contributions of building systems to different environmental impacts.

Case study Building. The case study building was Magee-Womens Hospital (MWH). MWH is a University of Pittsburgh Medical Center specialty hospital, opened primarily for women. Magee is one of the top women's hospitals in the United States and is ranked 9th for gynecology, with more than 10,000 babies delivery each year (US News & World Report 2015). The hospital is located in the Oakland neighborhood of Pittsburgh, Pennsylvania and has established green initiatives in recognition of Practice Green health and the U.S. Environmental Protection Agency's Office of Children's Health Protection recommendations. It is currently equipped with 360 beds, an emergency room and ambulatory facilities. The facility serves 2,500 employees and 1,500 medical staff (UPMC 2015). Figure 1 illustrates multiple views of the hospital building after modeling with the steps from the CAD stage to BIM and finally the LCA stage.

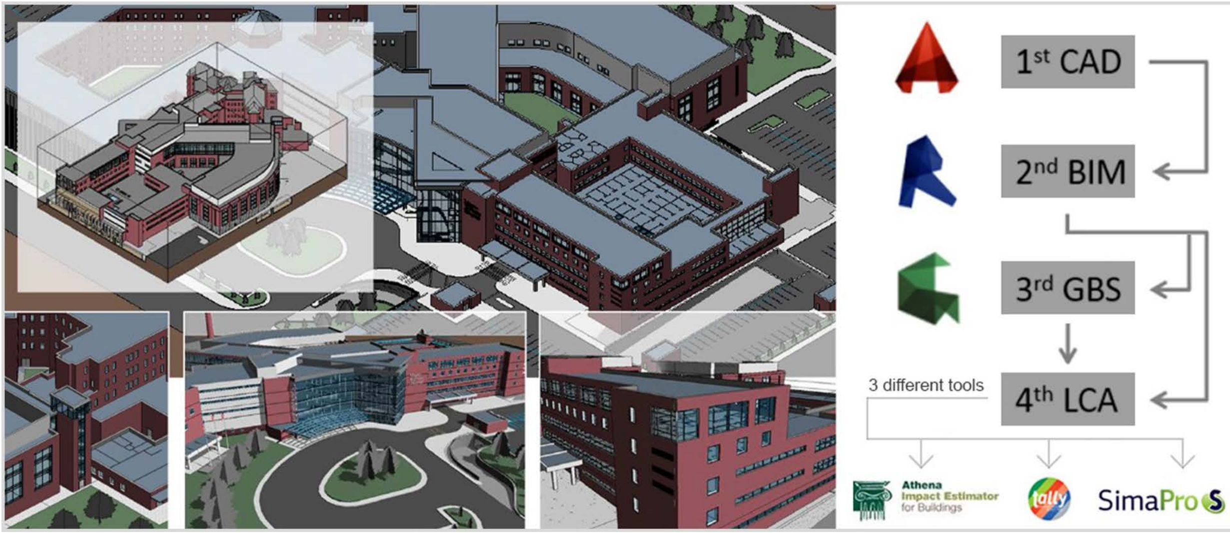

Figure 1. Multiple views of the case study building using BIM

The BIM model was developed using Autodesk Revit for the entire hospital building based on the CAD drawings that were obtained from hospital administration. The building consists of three wings with five floors above-ground and one floor underground with total occupancy of 8,000 users, total area of 957,927 ft^2 (291,976 m^2). To put the case study building in perspective, average US floor space of inpatient health care building is around 238,000 ft^2 representing 3% of the total floor space in all commercial buildings and 6% of the total primary energy consumption by commercial building (US EIA 2003). Also, average US energy expenditures per square foot for the same building type are $2.76 whereas MWH spend $3.76 per square foot. For the characteristics of the building, MWH has 183,754 ft^2 (56,008 m2) in roof space. The exterior wall area is 264,150 ft^2 (80,512 m^2). Fixed windows cover around 20% of the exterior walls, with an area of 55,269 ft^2 (16,846 m^2) and about 36% of them facing north. Operable windows cover around 0.6% of the exterior walls, with an area of 15,988 ft^2 (4,873 m^2) and about 18% of them facing north. Skylights cover about 1,524 ft^2 (465 m^2) of the roofs. Exterior doors cover around 0.006% of the exterior walls, with 1,723 ft^2 (525 m^2). The underground wall area is 52,023 ft^2 (15,857 m^2), with 201,462 ft^2 (61,406 m^2) of underground slabs. The modeling process took some time due to the large size of the hospital. The challenges included: modeling time due to the large size of the hospital, accessing complete drawing sets and documents from the hospital administration, and training in building science.

Building LCA software Tools & Life Cycle Assessment. Table 1 compares the key elements of the tools. The tools vary on LCA database use; for example, Athena primarily draws from U.S. LCI; Tally from GaBi; and SimaPro from multiple databases including ecoinvent.

In Athena and Tally, built specifically for building LCAs, the functional unit is by default, usable floor space of the building. The reference flow is the amount of material required to produce the hospital building, over the full life of the building. We assumed the life of the building to be 60 years (Aktas and Bilec 2012). Building elements with a shorter life span like interior finishes, doors and windows have been assigned replacement periods. Architectural materials and assemblies include primary materials and all additional materials required for the product's manufacturing and use (including hardware, sealants, adhesives, coatings, and finishing, etc.).

Table 1. Comparison of the general characteristics between the three tools used in study

Comparison Category	Impact Estimator for	Tally	PRé SimaPro
	Whole building analysis	Whole building analysis	Product analysis tool
Building Type	Industrial, Institutional, Commercial, Residential for both New Construction and Major Renovation	Any type including both New Construction and Major Renovation	complex life cycles
LCI Database	ATHENA Database (cradleto-grave), US LCI Database	GaBi LCI databases	US LCI Database; Ecoinvent; others available depending on purchase option
Data Location	Canada and US Region		
LCIA Method	EPA TRACI	Multiple (EPA TRACI, used)	Multiple (EPA TRACI, used)
Impact Categories	· Acidification · Potential Global Warming · Potential Human Health · Respiratory Effects Potential · Ozone Depletion · Potential Smog Potential · Aquatic Eutrophication Potential · Total Fossil Energy	· Acidification Potential · Eutrophication Potential · Global Warming Potential · Ozone Depletion Potential · Smog Formation Potential · Primary Energy Demand	· Climate change · Carcinogens · Respiratory organics · Respiratory inorganics · Radiation · Ozone layer · Ecotoxicity · Acidification /eutrophication · Land Use
Target Users	Architects, Engineers, Designers, Environmental Consultants	Architects, Engineers	LCA Practitioners, Researchers
Skill Level in LCA	Moderate	Advanced level in BIM	Advanced

From Table 1, we see that the three different tools vary in important aspects. The level of analysis category varies between Athena, Tally, and SimaPro; for example, with SimaPro the designer will need to complete a quantity estimate during design in order to complete the LCA, yet the other tools integrate this function in their LCAs. Different LCI databases from different geographical areas represent a common challenge in LCA, as Athena is North American focused and SimaPro is European focused with the largest database of ecoinvent. One important difference in the three tools is that Athena uses the LCIA method of TRACI, whereas Tally and SimaPro use multiple LCIA methods. Within the international green building rating systems, different LCIA methods can make the baseline building comparison problematic.

Results. The different LCA tools varied significantly in the likelihood that the design team could use them at early stages of the building design process and decision-making. In Table 2, we have documented advantages and disadvantages of the three LCA tools through a number of objective criteria. Some of the applications (ATHENA's Impact Estimator and PRé's SimaPro) rely on a bill of materials that change constantly in design alteration. However, some other (Kieran Timberlake's Tally) shows a greater advantage where it can be integrated from the beginning of the design process. Transparency was higher in SimaPro compared to others because users can access all inventory flows that include inputs of water, energy, and raw materials, and releases to air, land, and water. The level of experience of the user is also important. Athena does not require advanced BIM knowledge or deep LCA experience; Tally requires extensive BIM knowledge with moderate.

Table 2. Perceived advantages and disadvantages of the three tools used in study (darker means higher advantages)

LCA tool / Comparison component	Integrated with design	Transparency	Building Systems*	LCA Stages	Geographical area	LCA Experience
Athena Impact Estimator for Buildings						
Kieran Timberlake's Tally						
PRé SimaPro						

* Building systems that can be included in the LCA: structural, architectural, finishes, mechanical, electrical, and plumbing.

The Tally results (Figures 2 and 3) of the whole building LCA for Magee-Womens Hospital (MWH) show an important opportunity for decision makers to modify the design (when completed in the design phase) according to the LCA results. The current design is dominated by concrete and masonry which represent approximately 65% of the total mass of the building. However, significant impacts were from fenestrations, metals, and finish work. As shown in Figure 2, openings represent 1.5% only of the total mass of the building but represent 9% of the global warming potential and 50% of the ozone depletion potential. On the other hand, when considering the results from the point of the life cycle stage, we can see as shown in Figure 3, about 77% of global warming potential and 69% of the primary energy demand will occur during the manufacturing stage compared to 23% and 31% during the maintenance and replacement.

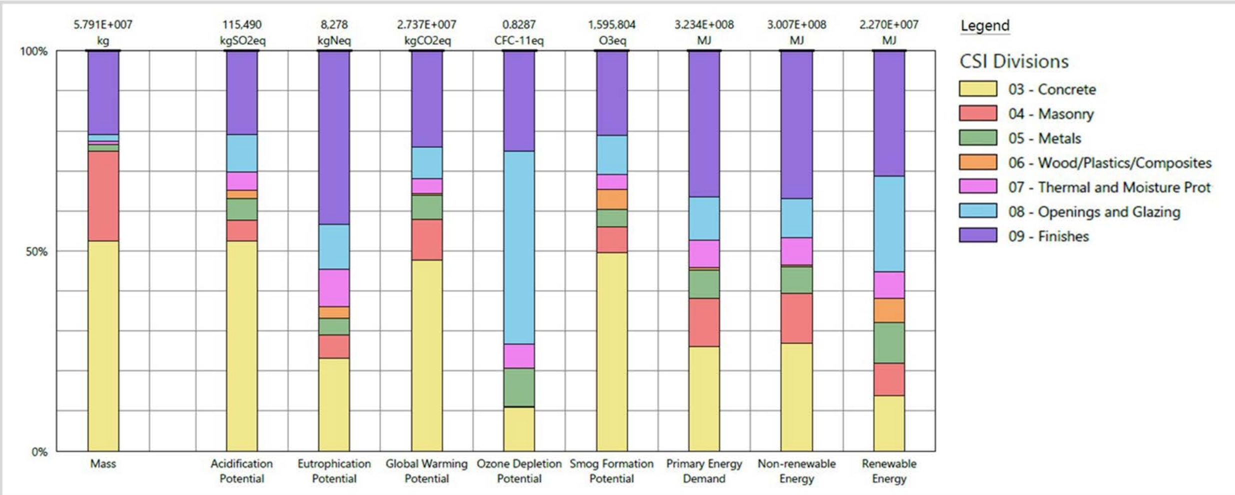

Figure 2: LCA results from Tally. MWH LCA results Itemized per CSI Division. (Use phase energy not included)

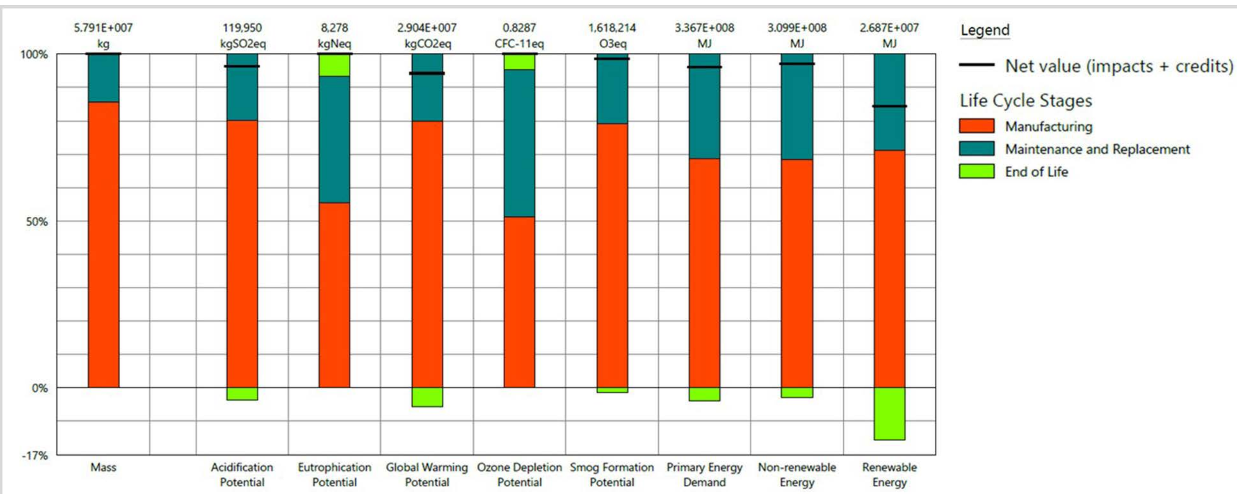

Figure 3: LCA results from Tally. MWH's LCA results Itemized per life cycle stage (Use phase energy not included)

Conclusion. In this paper, we completed a comparative evaluation of three commercially available building LCA software tools and completed an LCA of a case study building using Revit and Tally. We are expanding our work by completing the LCAs in Athena and SimaPro to elucidate the impact of LCA building software decisions in the context of green building rating systems. The preliminary results identify many challenges in the requirements of the various green building rating systems. One of the most important challenges is related to the question - if LEED requires a 10% reduction in impact categories from the LCA baseline building, will the comparative results fall within acceptable ranges, given the likely variability in the LCA building software results. One suggestion is that LEED could have minimum requirements regarding the LCA tool, assumptions, and scope in order to foster a comparable and comprehensive baseline. The integration between LCA tools and today's building design technology like BIM is important.

The significance of this research relies on the fact that 88% of BIM users expect their firms to use BIM on a green retrofit project (McGraw-Hill Construction 2010); which increases the need for similar research that help in BIM streamlining the LCA process for buildings and simplify/reduce time needed to conduct LCA using tools or methods exist today.

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