

A Framework of a Conceptual Roadmap for Standardization of Building Life Cycle Assessment Tools

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As sustainability became an integral part of the construction industry, the assessment of the project life cycle became a necessity. Various tools have been used by practitioners in life cycle assessment (LCA) which usually helps in achieving building certification credits. Even though there has been significant development in construction specific LCA tools, a standard framework has still not been established. This research aims at determining the factors which influence the choice of an LCA tool, by using case study of buildings. Following a rigorous assessment of successful sustainability tools in Europe, a similar approach to standardize the tools in United States helped formulate a set of evaluation criteria. Results obtained from different tools would help create the standardization matrix between the defined factors and the LCA tools. Limitations of this research are represented in system boundary definition, which would not affect the results as all platforms would be working on the same system boundary. Another limitation is the assumption that source of electricity would be from a regionalized grid, closest to the project location and neglecting the different sources from which the electricity is produced. Future research would aim to prioritize the factors determined in this paper and would be validated by using an Analytical Hierarchical Process (AHP) on a standardization matrix between the defined factors and various LCA tools.

Key Words: Life Cycle Assessment (LCA), LCA tools, Sustainability, Construction

Introduction

Life cycle sustainability assessment (LCSA) became a decisive factor for sustainability assessment standards after being adopted by United Nations Environment Program (UNEP) (Benoît-Norris et al., 2011; UNEP, 2011). LCSA evolved over years (maintaining the UNEP framework), and it’s economic, environmental and social elements began to be used in various fields including construction (Bozhilova-Kisheva & Olsen, 2012; Guinée, 2002; Kloepffer, 2008). Life cycle assessment (LCA) became widely used concept to compare building components. Past literature shows LCA being used for optimal material choice, optimal insulation thickness, and inter-region building comparison over life-cycle energy use etc… (Hasan, 1999; Monteiro & Freire, 2012; Norman, MacLean, & Kennedy, 2006). A unique study undertaken by researchers in United States and UK showed a comparative energy use over building’s life cycle (Junnila, Horvath, & Guggemos, 2006). Another study focused on delineating Life Cycle Inventories (LCI) which provide assessment standards for environmental measures in Europe and categorized different life cycle tools as generic, specialized and tailored (Rebitzer et al., 2004). In all past research studies, it is evident that various LCA platforms such as Open LCA, Athena Impact Estimator, GaBi, SimaPro, Umberto, BEES, EIO-LCA etc… have been used (Anand & Amor, 2017; Carmody, Trusty, Meil, & Lucuik, 2007; Rashid & Yusoff, 2015; Srinivasan, Ingwersen, Trucco, Ries, & Campbell, 2014). Using numerous tools and assessment techniques, Klöpffer (1997) compared ISO (used in US) and SETAC (used in Europe) for comparing various components of LCA. There are numerous LCA tools available in the market (Hollerud B., 2017), however, there is no standardized tool that could be used for life cycle assessment of buildings. This research aims to present a conceptual roadmap for preparation of a standardized framework for life cycle assessment while accounting for the contributing factors. A research done by Han and Srebric (2011) discussed the differences and similarities of using various LCA tools for buildings. Their research would serve as external validation to the standardization framework conceptualized in this paper.

Literature Review

Life cycle Sustainability Assessment Principles

UNEP adopted the sustainability viewpoint in 1992, which developed over the years to become Life Cycle Sustainability Assessment (LCSA) (UNEP, 2011). LCSA consisted of Life Cycle Assessment (LCA), Life Cycle Cost Analysis (LCC) and Social-Life Cycle Analysis (S-LCA). LCSA encompassed the pre-existing concepts into one principle (typically referred to as triple bottom line); environmental aspect represented in LCA, economic aspect represented in LCC and social aspect represented in S-LCA. LCSA framework has been widely discussed in various research studies pursued over next few years (Bozhilova-Kisheva & Olsen, 2012; Kloepffer, 2008).

According to ISO (2006), life cycle assessment is a technique to gage the environment impacts of any product by assessing the impacts from cradle-to-grave. A research done in Technical University of Crete, defines life cycle assessment as combination of all stages from extracting raw materials, their processing into finishes products, maintenance phase of the product and finally disposing or recycle of that product (ECOIL, 2004). EPA (2006) defines life cycle assessment as a “cradle-to-grace approach for assessing industrial systems that evaluates all stages of a product’s life. It provides a comprehensive view of the environment aspects of the product or process”. Assessing any product’s life cycle depends on the system boundary which can be defined as the set of unit processes included in the system and every unit process having elementary flows as its inputs and outputs (Suh et al., 2004). Klüppel (1998) defined elementary flows as the material/energy drawn/discarded from/into the environment without human interference. Assessment of any product’s life cycle also depends on the functional unit which could be defined as the unit of measurement of the final output from the system (ECOIL, 2004). The overarching purpose of performing a life cycle assessment is to compare the environment impacts of different options of making the final product (Guinée, 2002). Another aspect of LCSA, Life Cycle Cost Assessment (LCC) calculates the total cost through the product’s life cycle; system boundary being same as in LCA (Kloepffer, 2008). Norris (2001) mentioned in a LCA-LCC integrative research that LCC is used to compare multiple paths of producing a particular product from an economic viewpoint. In a report published by Stanford University, life cycle cost analysis was defined as “a process of evaluating the economic performance of a building over its entire life” (Standord, 2005). After UNEP introduced the triple bottom line (environmental, economic and social), research relating to the framework and assessment of S-LCA were published. Stakeholders involved in a particular project can be great input for assessing the social impacts. UNEP/SETAC define five main impacted groups from any project/product, namely workers, local community, consumers, society, and value chain actors (Benoît-Norris et al., 2011; UNEP, 2011). In Benoît-Norris et al. (2011), LCA and LCC has been used for comparison of various platforms over the system boundary.

LCA in Construction Industry

With focus turning towards sustainability after UNEP introducing the LCSA in 1992, researchers began to focus on finding methods to conserve energy for an operational building. Hasan (1999) optimized the insulation thickness using the LCC technique, by comparing the increase of thickness of insulation cost with total cost of fuel used for heating and air-conditioning. One of the biggest impact factors in assessing the life cycle is greenhouse gas emissions; a study comparing low and high residential density used life cycle assessment to estimate the greenhouse gas emissions for both scenarios and found that low density residential entities are more energy intensive and have greater impacts on the environment compared to high-density settlements (Norman et al., 2006). An LCA could be performed at a system level or at a unit level; a research done by Bilec, Ries, Matthews, and Sharrard (2006) performed a hybrid-LCA (combining the unit and system level) or assess the construction process using the case study of a parking structure. Considering the data scarcity for design phase, Rodrigues, Kirchain, Freire, and Gregory (2018) determined the contributors to the design phase by an attribute-to-activity modelling. Building on this research, environment impacts were seen for various building systems for the design phase by assessing carbon footprint, emissions and global warming among other factors (Žigart, Lukman, Premrov, & Leskovar, 2018). A unique research done by Junnila et al. (2006) compared the life cycle of buildings in US and Europe to conclude that they use comparative energy and resulted in proportional emissions. LCA being a cumbersome process; researchers have tried to simplify by just considering a part, in the whole life cycle (Malmqvist et al., 2011). Life cycle of any product is analyzed based on impact assessment methods defined by previous researchers, wherein guidelines for using the methodologies have been clearly defined (Bribián, Capilla, & Usón, 2011; Hischier et al., 2010). Monteiro and Freire (2012) published a research which compared different options for wall types and juxtaposed three different impact assessment methods. They found that global warming potential had a good correlation among all three methods, but they failed to correlate for Eco-toxicity and human toxicity. Measuring life cycle impacts could be done using a variety of tools, as discussed in the next section.

Frequently used LCA Tools

Various LCA software have been used over the years to assess the building's life cycle. Carmody et al. (2007) used Athena Impact Estimator for assessing the life cycle of different building assemblies. Another study used Athena Impact Estimator and Economic Input-Output LCA (EIO-LCA) model to determine different energy assessments that could be extracted from those platforms (Srinivasan et al., 2014). EIO-LCA has been also used by Norman et al. (2006) analyzed the greenhouse gas emissions for high and low density residential housing. A recent study showed that various tools like GaBi, SimaPro, Umberto NXT, Open LCA, EIO-LCA and the Boustead model could be used for any life cycle analysis. Some building specific tools such as Athena Impact Estimator, LEGEP, Envest, ECOSOFT, BeCost, BEES, EQUER, EcoEffect and ECO-BAT could be used (Anand & Amor, 2017; Rashid & Yusoff, 2015). Open LCA is preferred by researchers being an open source platform providing a wide variety of applications (Braunwarth, Amrhein, Schreck, & Kaloudis, 2015; Ciroth, 2007; Ingwersen, 2012; Zastrow, Molina-Moreno, García-Segura, Martí, & Yepes, 2017).

Methodology

Based on studies cited above, it became evident that some of the widely used LCA tools needed to be compared to decide on a potential tool encompassing all LCA dependent factors. For this study, Open LCA, Athena Impact Estimator, BEES, EIO-LCA and GaBi would be used for comparison using two case studies. Figure 1 shows the methodology map used for this research.

The study starts with defining the scope having various elements. Functional unit used for this study is (per square feet*per year), which normalizes the time scale of various phases of the building, used in this study. The necessity of such a normalization arises due to high duration variability for design, construction and operation & maintenance phases. Short-termed temporal scope is defined for this research as all tools required for this study have already been developed and used in previous studies. Geographic scope has been limited to Colorado due to ease of data collection, however, it can be easily expanded for other regions of the United States, or even some international locations. System boundary definition ensued as the life cycle needs to be analyzed over a defined system boundary. The system boundary for this research is shown in figure 2, comprising of three phases namely the design phase, construction phase and operation & maintenance phase (OM phase) of any building. Design phase is the shortest phase of the building's life cycle and the OM phase is the longest phase. Inputs for each of design, construction and OM phases, as shown in figure 2 are decided based on the elementary flows that can have significant environmental impacts. Electricity consumption (for running office) and transport (trips to and from project site) would be the only inputs for the design phase. Materials used in construction, electricity consumption (for operating various tools and equipment), truck transport (for hauling materials to the site and waste from the site), and water consumption (both drinking water and water used in construction) are the inputs for construction phase. Fuel consumption (for running generators and other equipment), natural gas consumption (for running the heating systems), and water consumption (for restrooms, labs etc.) are the input for OM phase.

Data analysis using various LCA tools like Open LCA, EIO-LCA, Athena Impact Estimator, BEES and GaBi, to assess the life cycle impacts and the life cycle costs would be done. Based on inherent methodologies followed by LCA tools under consideration, a list of significant factors are noted. These factors would provide a basis of comparison of various LCA tools, in order to determine the tool which could be used for a standardization framework.

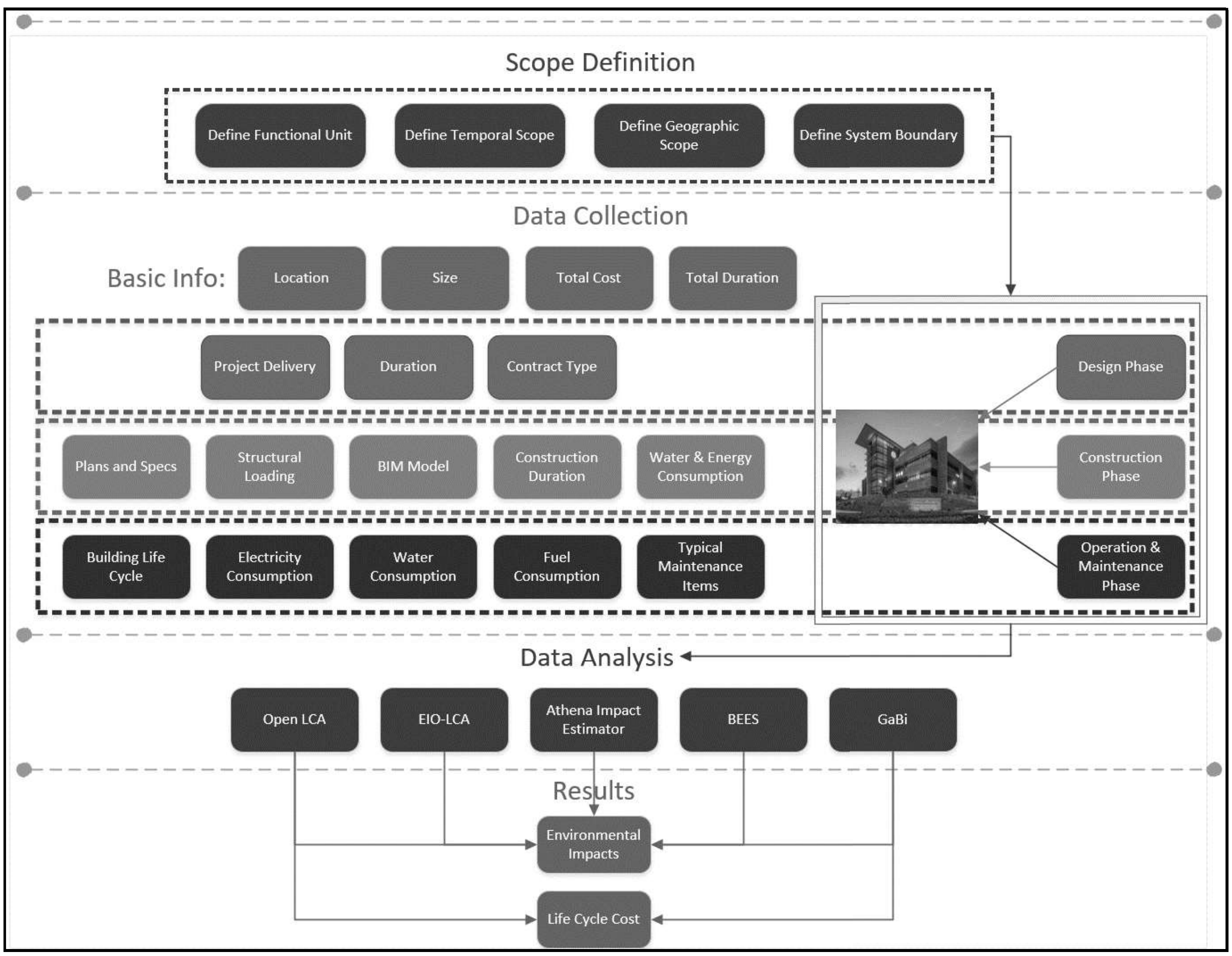

Figure 1: Methodology Map

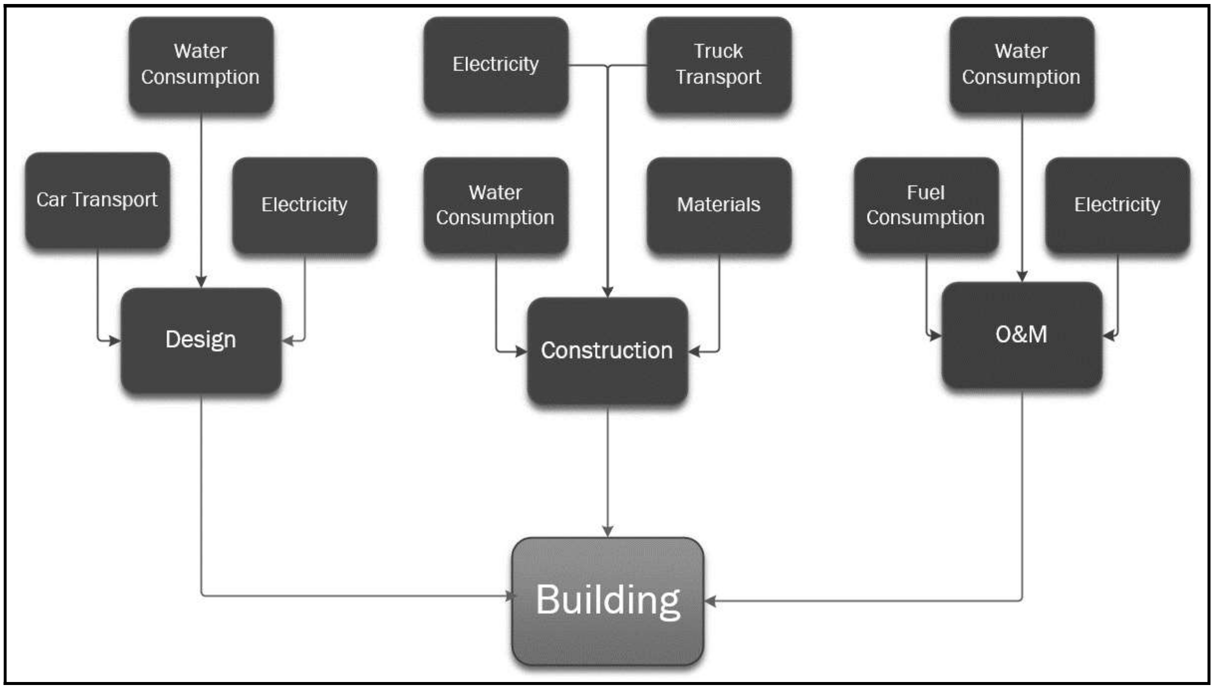

Figure 2: System Boundary

Two case studies would be used for the purpose of this research. A comprehensive data collection would be done, comprising of data needs for all three phases in the system boundary (as discussed in figure 2), followed by data processing for various LCA tools used. Details of data needed can be seen in figure 1, which can be used for data analysis. All platforms would be used to compare the life cycle impacts; Open LCA and GaBi would be used to compare the life cycle cost. Thereafter, the dependency matrix would be filled for various tools (for each of the case studies).

Discussion and Anticipated Results

Data analysis would be implemented using relevant and current buildings' data (case studies) which would be serve as a controlled input into each of five platforms, and environmental impacts would be estimated. Open LCA being dynamic, can work with numerous impact assessment methodologies, for instance, CML baseline, Cumulative Energy Demand, TRACI, ReCiPe etc. EIO-LCA works on the premise of North American Industry Classification System (NAICS) categories to estimate the total energy demand, greenhouse gases, land use, impacts using TRACI methodology etc. Athena Impact Estimator estimates the environmental impacts based on TRACI methodology. GaBi uses Ecoinvent database to assess the environmental impacts making it easier to use TRACI, cumulative energy demand etc. Various impacts assessed by different platforms would be compared to see the correlation between results from different platforms. Another comparison would be done between similar impacts assessed by the same platform using different impact assessment methods. Some LCA platforms like Open LCA and GaBi have a provision for assessing the life cycle cost (LCC). Thereafter results will be compared which are obtained for LCC from Open LCA and GaBi with each other. Based on the functionality of platforms in consideration (represented in input data and expected results), table 1 shows some factors that can be used as the basis of standardization of platforms for life cycle assessment of buildings. These standardization factors are based on the type and amount of data that needs to be input in most widely used LCA software.

Table 1: Standardization Factors

Factors	Explanation
Data Comprehensiveness Required	Amount of data needed to be entered to get satisfactory results
Geographic Scope Variability	Selection of project location
Choice of life cycle impact databases	Availability of choice of different databases containing various databases for assessing life cycle impacts, such as Ecoinvent, NREL etc…
Inputs Regionalization	Defining the geographic source of various inputs
Unit level vs System level modelling	Ease of switching from/to unit and system level model
Availability of Impact Assessment methods	Availability of choice of different impact assessment methods such as TRACI, ReCiPe etc…
Cost Uncertainty	Option of entering a range of costs (min and max.) and running probabilistic simulations
Array of Results Available	Various results that the platform can produce with same amount of data entry
Breakdown of LCA results by phases	Potential of the platform to divide the impacts by the phases inside the system boundary
Future Analysis Potential	Export of Data/Results to Excel
Cost of Platform used	Cost of platforms; availability of student version
Usefulness in Multiple Project Phases	Usefulness of the platform in different phases of the building i.e. design phase, construction phase etc…

Conclusion

This research provided a conceptual roadmap to conduct a standard comparative process development for analyzing the life cycle of buildings using various LCA platforms. Through this study, the authors develop a framework to choose a standardized tool for life cycle analysis of a building. The factors defined above in table 1 provide a premise for standardization of a life cycle assessment tool by tabulating the factors against various platforms that would help in informed selection. This would provide the construction industry with valuable tool that could be used irrespective of location and the type of project. Building on past European studies, this research intends to root itself in US Construction Industry for easy Life Cycle Assessment by the stakeholders. The research has great applications in other fields as well, by providing the roadmap to a framework that could help develop field specific standardized tools (such as for manufacturing, heavy civil projects etc…). This would provide an industry-wide increase in use sustainable methods for lowering environment impacts in United States. Few limitations of this study could be not considering the demolition phase in the life cycle, assumptions that would be made for input variables for electricity and water consumption. Since all platforms would be assessed on one system boundary, the results obtained would still be coherent. Electricity above, for instance, is supplied from a grid which receives input from coal fired plant, natural gas plant etc…, hence rendering it difficult to separate the electricity obtained from different inputs. Hence for the purpose of this research, only the electricity grid would be regionalized to ensure the selected is closest to the project site. Future research could aim at prioritizing the factors on a Likert scale by using qualitative methodology represented in survey analysis (experts who use the platforms regularly), and validating them using an Analytical Hierarchical Process (AHP) model. Another future study could be applying a similar framework for a heavy civil project and standardizing their life cycle assessment framework.

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