



Three Types of Buildings, Three Tools: Why Does Building Life Cycle Assessment Need Standardization?

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Abstract

The growth of global construction necessitates robust environmental impact assessment methods. Yet inconsistencies in life cycle assessment (LCA) tools limit benchmarking, particularly in Asian regions. This study addresses this need by conducting a comprehensive evaluation of three widely used life cycle assessment (LCA) tools: Athena IE, One Click LCA, and eTool LCD applied to Sri Lanka's most common building types: office, apartment, and residential buildings. Furthermore, through a comparative analysis, it identifies software-specific limitations and establishes performance rankings for the three tools based on five published evaluation themes. The study focuses on four critical impact categories: global warming potential (GWP), acidification potential (AP), and eutrophication potential (EP). The analysis revealed tool-dependent variations of up to 15% in GWP values (office: 13.4-22; apartment: 25.3-35.2; residential: 9.7-12.6 kg CO₂-eq/m²/year), primarily resulting from differences in regional databases and calculation methodologies. Consistent with established literature, the use stage (B1–B7) emerged as the dominant contributor (>75%) to GWP among the selected building types, followed by the product stage (A1–A3). The systematic evaluation ranked One Click LCA highest (90%), with eTool LCD (75%) and Athena IE (62%) demonstrating specific limitations in regional applicability. These findings highlight the importance of tool selection in emission assessments. Also, it

underscores the urgent need for standardized LCA protocols in tropical developing regions. For practitioners, this study provides guidance for selecting LCA tools.

Keywords: Whole building life cycle assessment tools; sustainable building; building emissions; global warming potential, Athena IE, One Click LCA, eTool LCD

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1. Introduction

Whole Building Environmental Life Cycle Assessment (WBELCA) Software Tools (STs) are pivotal in overcoming complexities of sustainable design, offering critical support for multi-stage decision-making while balancing comprehensiveness, user-friendliness, and environmental impact reduction [1]. This can only be achieved through the correct decisions taken by the stakeholders involved at the planning and designing stages [1]. WBELCA involves modeling the full life cycle of the buildings, from material extraction to construction, operation/maintenance, demolition, and disposal. However, Whole Building Life Cycle Assessment (WBLCA) is still not a common practice in the construction sector in majority, due to numerous reasons. The misconceptions, such as loss of productive design time, the need for expert knowledge in life cycle assessment (LCA), and elevated costs could be the most prevalent excuses for not performing WBLCA by many builders in the Asian region. STs specially designed for conducting the WBLCA have become a versatile solution to overcome such challenges. Elodie in France, Eco-Bat in Switzerland, Eco-Quantum & Greencalc in the Netherlands, BEAT 2002 in Denmark, EQUER in France, Envest 2 in the UK, and LEGEP in Germany [2], [3] are some of the WBELCA STs that have been developed in the 21st century. Japan's J-CAT and China's CBCM use local methodologies. New Zealand's BRANZ LCA Quick streamlines assessments using its own data. International platforms like One Click LCA and eTool LCD have gained attention for their cloud-based collaboration and broad certification support. In the US, tools like Tally and Athena IE enhance architectural workflows through BIM integration. Germany's ÖKOBAUDAT and eLCA standardize performance evaluations using national declarations. These tools are also used for various purposes such as eco-design, the accomplishment of credits in Green Building certifications for building materials and buildings, which includes Environmental Product Declarations (EPD). Thus, adoption of these STs enable better design choices with improved environmental performance during whole life cycle of buildings [4].

According to a previous study, most of the ST applications are limited to European and American continents, with very few in the Asian region [1]. Further, comparative building LCA studies are lacking in Asian countries like Sri Lanka. However, such studies are of major importance, as they allow users to recognize inconsistencies and uniformities in using different environmental impact databases. It also shows that the LCA ST choice has a significant impact on the environmental impacts obtained [5]. Thus, to address this gap in the existing published data, this study aims to analyze the most widely constructed building types in Sri Lanka using the most commonly practiced LCA tools.

The objectives of this study are:

1. Explore the most commonly used WBLCA tools
2. Analyze the effectiveness of using regionally available WBELCA-STs to analyze the environmental sustainability of the three buildings in three types in Sri Lanka
3. Assess and rank the WBLCA tools based on the thematic areas based on well-published literature

2. Methodology

The methodology was a four-step process which consists of selecting three most commonly used WBELCA tools through a thorough literature review, selecting the most constructed building types in Sri Lanka within last two decades, running the life cycle analysis for the selected three buildings using the selected three tools according to ISO 14040 and 14044 standards and rank the selected tools based on published criteria.

2.1. Selection of Three WBELCA-STs

A comprehensive literature review was conducted to identify the total number of WBELCA STs available through Scopus and Science Direct databases. Based on the search criteria, sixteen WBELCA STs were identified as up-to-date software tools published in research or review articles over the past two decades [1]. These include Athena Impact Estimator, Tally, One Click LCA, EQUER, ELODIE, COCON, Eco-bat, Greencalc, GaBi Built IT, Eco Quantum, Envest, LEGEP, BeCost, ECOSOFT, SBS, and eTool LCD. These were comprehensively analyzed by the scholars [1], [5], [6] based on key attributes, including the software platform user requirements and expertise level, applicable project types, licensing terms, and geographical applicability. Among those, thirteen originated from the European region, two provided geographical coverage for the American region, and one was developed in Australia.

Table Table 3: Comparison Between Three Selected Tools indicates a comparison between three selected tools. From the European tools, One Click LCA was chosen for its unrestricted applicability to any building type and free student license access, making it ideal for global and academic use. eTool LCD was selected for its global coverage, rich template library, and compatibility with design tools and BIM, which streamlines data collection. Additionally, the software supports BIM integration, enabling direct data transfer from 3D design software, thereby streamlining the inventory collection process. Finally, Athena Impact Estimator (IE) was selected from the two American-based tools. Athena IE was selected as the third tool due to its unique position, user-friendly nature, and capability of assessing entire buildings using standard LCA methods. Unlike Tally, which requires advanced Revit skills and a paid license, Athena IE is accessible to a broader range of users, making it more practical for widespread application.

2.2. Selection of Most Commonly Constructed Building Types in Sri Lanka

The study analyzed buildings constructed over the past two decades by five top-tier Sri Lankan construction companies classified under the CS2 category of the Construction Industry Development Authority (CIDA), Sri Lanka [7]. The selected companies, International Construction Consortium (Pvt) Ltd, Maga Engineering (Pvt) Ltd, Tudawe Brothers (Pvt) Ltd, Sanken Constructions (Pvt) Ltd, and the Central Engineering Consultancy Bureau, were chosen for their significant industry impact, large project portfolios, and strong financial records [2], [3], [4], [8]. As illustrated in Figure 2, a total of 32 apartment buildings and 16 office buildings were constructed. Additionally, six hospital buildings, 11 educational buildings, five hotel buildings, and six commercial buildings were recorded within the time period.

The analysis of building projects over the past two decades shows that office, apartment, and educational buildings are the most frequently constructed types, indicating consistent demand. Office and apartment buildings demonstrate a steady upward trend, especially after 2014, while educational buildings appear more irregularly,

with spikes in 2020 and 2023. Other building categories, including hospital, educational, hotel, and commercial buildings, become more prominent after 2015, demonstrating a diversification in the construction sector. However, a sharp decline in completions after 2021 suggests the impact of economic challenges and industry-specific issues on construction activity. In addition to these large-scale building projects, single-family residential housing remains one of the most prominent types of construction in Sri Lanka, as reported by the Department of Census and Statistics[9]

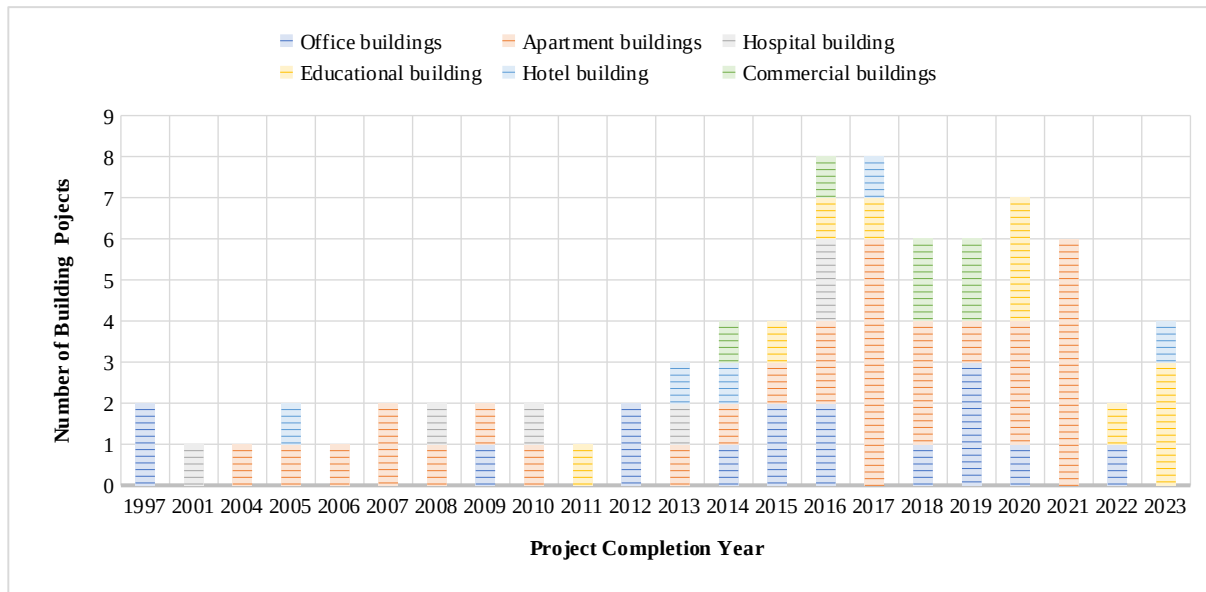


Figure 1. Constructed Building Projects in Sri Lanka from 1997-2023 through

Thus, carefully considering this trend in building construction, for the current study, a single-family residential house building (Building 1), an apartment building (Building 2), and an office building (Building 3) were selected to conduct the assessment. The selected buildings are located in Colombo as it operates as Sri Lanka's commercial and financial hub, contributing nearly 50% of the nation's GDP and hosting a significant portion of its industries [10]. Specifics of the selected buildings are attached to Annexure 1.

2.3. Life Cycle Assessment

2.3.1. Goal and Scope Definition

The analysis was conducted within a cradle-to-grave system boundary, considering construction stage (A4–A5), use stage (B1–B7), end-of-life stage (C1–C4), and benefits. These life cycle stages are detailed in Figure 2. The study considered Global Warming Potential (GWP) (kg CO₂-eq), Acidification Potential (AP) (kg SO₂-eq), Eutrophication Potential (EP) (kg PO₄-eq) impact categories while the functional unit was defined as one square meter (m²) of gross floor area per year, ensuring comparability across different building types. Further, the life span was assumed to be 50 for all three buildings [11]. Input data are included in Annexure 2.

Figure 2 shows a comparison of the three selected LCA tools, and it reveals significant differences in their coverage of various life cycle stages. While all tools follow a cradle-to-grave approach and assess stages such as raw material extraction, transport, manufacturing, construction, and deconstruction, their depth of coverage varies. Regardless of the tool used, raw material extraction, transportation to the site, manufacturing, construction impacts, and deconstruction processes are consistently analyzed. Notably, all three tools assess sustainability beyond the building's operational life by considering potential environmental benefits of recycling and reuse (D). However, Athena IE limits its full coverage only to the replacement (B4) and operational energy use (B6) under the operational stage. Moreover, One Click LCA offers the most comprehensive coverage across all stages, making it the most robust for long-term impact assessments, while eTool LCD covers nearly all stages except refurbishment (B5).

	Building Assessment Information															
	Product Stage			Construction Process Stage		Use Stage							End of Life Stage		Benefits & loads beyond the system boundary	
	Raw Material Supply		Transport	Manufacturing		Transport	Construction-installation process		Use	Maintenance		Repair	Replacement		Refurbishment	Operational Energy use
	A1	A2		A3	A4		A5	A5		B1	B2	B3	B4	B5	B6	B7
Athena IE	Y	Y	Y	Y	Y	Y	Y	Y	N	P	N	Y	Y	N	Y	N
One Click LCA	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
eTool LCD	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
	Reuse/recycling/recovery potential															D
	Y															Y

Figure 2: Comparison of the three selected LCA tools based on the building assessment information

(Y – Yes, support, N – No, doesn't support, P – Partially supported)

2.3.2. Life Cycle Inventory Analysis (LCI)

The data for the LCA analysis was sourced from the bills of quantities (BOQ) and the structural/architectural drawings (Annexure 3). The annual energy and water consumption during its operational stage were estimated based on a published methodology [12]. The annual energy consumed (Q) by each building was calculated using Equation (1) [1].

$$(1)$$

Where,

is heat release W/m²;

is the building's number of occupied hours per 24-hour day;

is the building's number of days of occupancy per week.

Table 1. summarizes the building characteristics as per the details from BOQs and the structural/architectural drawings for each building.

Table 1: Building characteristics of case study buildings

Building Parameter	Specifications		
	Building 1 (Office Building)	Building 2 (Apartment Building)	Building 3 (Residential Building)
Number of Floors	07	06	03
Location	Colombo, Sri Lanka	Colombo, Sri Lanka	Colombo, Sri Lanka
Gross Floor area (m ²)	4934	5198.6	979
Total height (m)	21.0	18.3	7.9
Frame structure	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete
Service life (years)	50	50	50
Foundation Type	Pad Footing	Pile Foundation	Strip Footing
Wall	Block masonry wall	Brick masonry wall	Brick masonry wall
Ceiling Type	Asbestos-free cement board ceiling	Aluminum-framed grid ceiling with gypsum board	Gypsum Board Ceiling Work
Finishes	Non-slip porcelain tiles, ceramic tiles, cement lime & sand wall plaster	Non-slip ceramic tiles, porcelain tiles, cement render, cement sand wall plastering	Ceramic tile, cement render, cement sand wall plastering
Doors and Windows	Timber, Aluminum glass doors & windows	Timber, aluminum-framed glass doors & windows.	Timber glass doors & Windows

2.3.3. Life Cycle Impact Assessment (LCIA)

Table 2 provides a comparative analysis of three LCA tools with respect to their assessment of various environmental impact categories. Majorly of the tools identified midpoint categories, that represent specific environmental stressors, and endpoint categories, that summarize environmental consequences. At the end of the LCIA, the emissions for midpoint categories relevant to each of the three WBELCA ST are displayed. The emissions for impact categories generated were organized based on life cycle stages (as per BS EN 15978 [13]). In addition, the results of the main impact categories GWP (kg CO₂e / m² / year), AP (kg SO₂e / m² / year), and EP (kg PO₄e / m² / year) were compared by normalizing the emissions by considering the three buildings with the same LCA tools.

2.4. Evaluation Criteria for Analyzing Three LCA Software Tools

The evaluation criteria developed [1] were used to assess the three tools: One Click LCA, Athena IE, and eTool LCD. The questionnaire incorporated three key software attributes, such as comprehensiveness of the LCA approach, user-friendliness, and contribution to sustainable design, which were evaluated across five thematic areas with 55 total questions. Each tool was scored by the authors in Sustainability and the Built Environment using a 3-point Likert scale: 0 (Disagree), 1 (Partially agree), 2 (Agree), and 3 (Strongly agree).

3. Results and Discussion

3.1. Comparative Environmental Performance of Three Building Types

This section presents and discusses a comparison between three selected tools and the life cycle assessment (LCA) results for selected office building (Building 1), an apartment building (Building 2), and a residential building (Building 3). The results, categorized by life cycle stages and impact categories, are analyzed from the selected three LCA software platforms: Athena IE, One Click LCA, and eTool LCD.

Table 3 indicates a comparison between three selected tools. From the European tools, One Click LCA was chosen for its unrestricted applicability to any building type and free student license access, making it ideal for global and academic use. eTool LCD was selected for its global coverage, rich template library, and compatibility with design tools and BIM, which streamlines data collection. Additionally, the software supports BIM integration, enabling direct data transfer from 3D design software, thereby streamlining the inventory collection process. Finally, Athena Impact Estimator (IE) was selected from the two American-based tools. Athena IE was selected as the third tool due to its unique position, user-friendly nature, and capability of assessing entire buildings using standard LCA methods. Unlike Tally, which requires advanced Revit skills and a paid license, Athena IE is accessible to a broader range of users, making it more practical for widespread application.

Table 2: A Comparative Analysis of three Life Cycle Assessment (LCA) tools according to the end-point and mid-point categories (Y represents the categories evaluated by the software.)

	End-Point Category								
	Human Health			Biodiversity/ Ecosystem			Natural Resources		
	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool	Tool
	1	2	3	1	2	3	1	2	3
Midpoint Category	Global Warming Potential	Y	Y	Y	Y	Y	Y		
	Ozone Depletion Potential	Y	Y	Y					
	Formation of Ozone in the Lower Atmosphere	Y			Y				
	Acidification Potential				Y	Y	Y		
	Eutrophication Potential				Y	Y	Y		
	Total Use of Primary Energy							Y	Y
	Biogenic Carbon Storage							Y	
	Photochemical Ozone Creation Potential		Y			Y			
	Abiotic Depletion Potential - Fossil Fuels							Y	
	Abiotic Depletion Potential - Elements							Y	
	Smog Potential			Y			Y		
	Human Health Particulate			Y					
	Fossil Fuel Consumption								Y
	Non-renewable Energy								Y

1: One Click LCA, 2: eTool LCD, 3: Athena IE

Table 3: Comparison Between Three Selected Tools

Software	Athena IE	One Click LCA	eTool LCD
Criteria			
Software Platform	Stand-alone software	Web-based	Web-based
Software Developer	Athena Sustainable Material Institute	One Click LCA Ltd.	eTool
Country of Origin	Canada (North America)	Finland	Australia
Availability of the tool	Free	Paid License with a trial, however, a free student license is available with limited features.	Free
System Boundary	Cradle to Grave	Cradle to Grave	Cradle to Grave/ Cradle to Cradle
Project Type	Residential, Office, Hotel Buildings.	All types of buildings	All types of buildings
Databases	Athena LCI Database	All verified type III EPD, including paid BRE IMPACT databases	Australian LCI database with an Eco Invent shadow database, IMPACT EN15804 database (BRE)
Life Cycle Capabilities	Whole Building Assessment	Whole Building Assessment	Whole Building Assessment
Characterization Model	US EPA TRACI	CML	CML

3.1.1. Global Warming Potential (GWP)

A comparison of GWP across buildings and software tools shows the use stage (B1–B7) as the dominant contributor to overall carbon emissions (Figure 3). In Building 1, GWP during this stage ranged from 2.51×10^6 to 2.80×10^6 kg CO₂-eq among the tools, with similarly high values in Building 2 (6.59×10^6 to 9.15×10^6 kg CO₂-eq) and Building 3 (4.31×10^5 to 4.97×10^5 kg CO₂-eq).

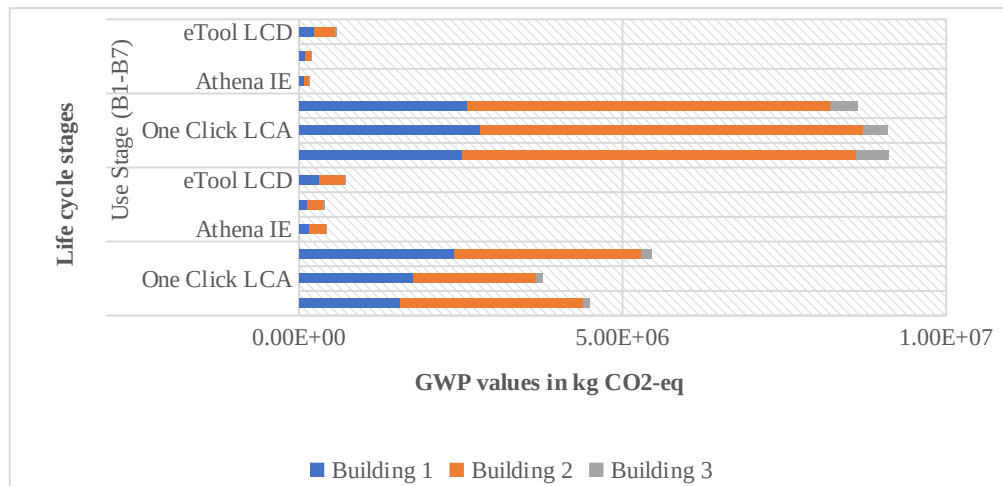


Figure 3: Contribution to GWP by Life Cycle Stage Across Buildings in kg CO₂-eq.

The results emphasized the operational phase as the primary source of emissions in built environments [14], [15]. The high GWP from the use stage arises from operational energy and water demands, which outweigh initial material and construction impacts over a typical building lifespan. One Click LCA generally reported higher GWP during the use stage for Buildings 1 and 2. This tool incorporates all sub-stages (B1–B7), including maintenance, repair, replacement, refurbishment, and operational energy and water use, providing a broader accounting than the other tools. eTool LCD does not include some sub-stages (notably use and refurbishment), occasionally leading to lower reported emissions. Athena IE omits several sub-stages in the use and end-of-life phases, resulting in systematically lower GWP estimates. Athena’s default regional assumptions (specific to North America) for transportation further reduce reported impacts.

Despite these methodological differences, the total GWP results for each building were of the same order of magnitude across all platforms (see Table 4). The percentage difference in GWP ranged from 10% for Building 1 to 16% for Building 3, consistent with findings by Giorgi et al. (2022), who observed up to 20% methodological discrepancies across widely used LCA tools.

Table 4: Total GWP Comparisons for Buildings Across LCA Tools in kg CO₂-eq.

	Athena IE	One Click LCA	eTool LCD
Building 1	4.52E+06	5.43E+06	3.31E+06
Building 2	8.34E+06	9.15E+06	6.59E+06
Building 3	6.15E+05	5.61E+05	4.77E+05

3.1.2. Other Impact Categories

Acidification Potential (AP) and Eutrophication Potential (EP) followed similar distribution patterns as GWP. The use stage consistently dominated, reaffirming the significant role of building operation in total impact (Figure 4, Figure 5).

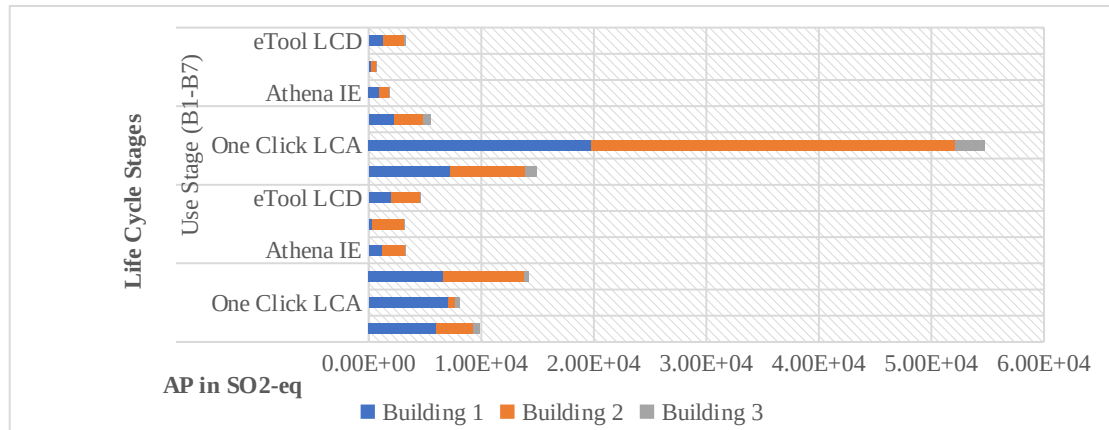


Figure 4: Contribution to AP by Life Cycle Stage Across Buildings in kg SO₂-eq.

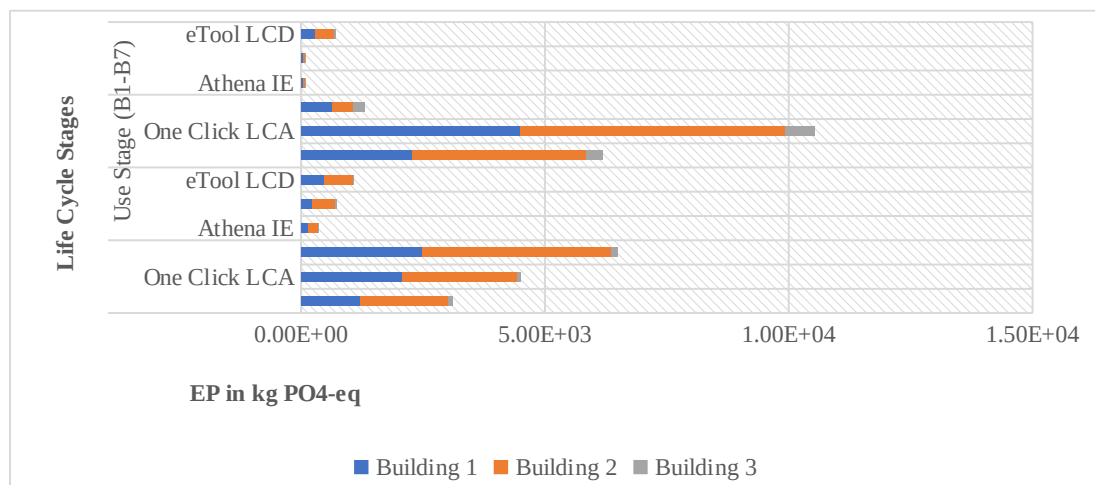


Figure 5: Contribution to EP by Life Cycle Stage Across Buildings kg PO₄-eq.

3.2. Data and Methodological Consistency Across LCA Tools

Despite the methodological and database differences among Athena IE, One Click LCA, and eTool LCD, all three produced reasonably consistent results for each building. The greatest variation observed was a 16% difference in Global Warming Potential (GWP) values among the tools. This comparability is attributed to their compliance with international standards (ISO 14040/44, EN 15978) [13], [16].

However, some limitations and sources of uncertainty were identified.

- **Database and Regional Coverage:** None of the tools has full access to region-specific environmental product declarations (EPDs), causing the use of proxy data and increasing uncertainty [17].
- **User Input Flexibility:** Athena IE does not allow customized transport inputs, defaulting to regional averages. This can lead to underestimation or overestimation in non-North American contexts [18].
- **Inventory Limitations:** All tools have limited local data for glazing, concrete grades, membrane and paint types, affecting material impact calculations [19].
- **User Experience:** Athena's data input interface creates difficulty with unit mismatches. One Click LCA's student version is not fully featured.

- Time and Resource Intensive: Completing inventory data remains a significant barrier for accurate LCAs, as previously reported [20], [21].

The findings confirm that operational phase impacts outweigh embodied impacts in the life cycle profile of contemporary buildings. Thus, there is a necessity to focus on operational efficiency for meaningful carbon reductions.

Consistent with high-impact studies, data quality, tool transparency, and methodological harmonization are essential for reliable cross-tool comparison and actionable results [22]. Stakeholders must be aware of current database limitations and push for better region-specific EPD coverage and streamlined data entry systems to enhance the utility and accuracy of digital LCA tools.

3.3. LCA Software CA Software Tool Assessment with Evaluation Criteria

This section represents the graphical results of the study done under the evaluation criteria developed by [1] to assess WBELCA STs focusing on three key attributes; comprehensiveness of the LCA approach adopted, user-friendliness, and contribution for sustainable design with respect to five main themes; data input, data analysis & interpretation, output results, tool structure, and database.

Table 5 presents the scores of each WBELCA software tool across the five main evaluation themes, based on a scoring scale ranging from 0 to 3 for each criterion. One Click LCA tool has the highest overall score while Athena IE has the lowest score.

Table 5: Scores for each LCA software tool based on the Evaluation Criteria

Main Themes	Athena IE	One Click LCA	eTool LCD
Data input theme	24	33	31
Data analysis and interpretation	13	22	16
Database	17	22	17
Tool structure	38	52	43
Database	11	20	18
Total Scores for each Software tool	103	149	125

Figures 6,7, and 8 represent the results obtained after evaluating each LCA software tool based on the three key attributes with respect to the five themes.

Figure 6: Comparison of tools based on Comprehensiveness of LCA approach

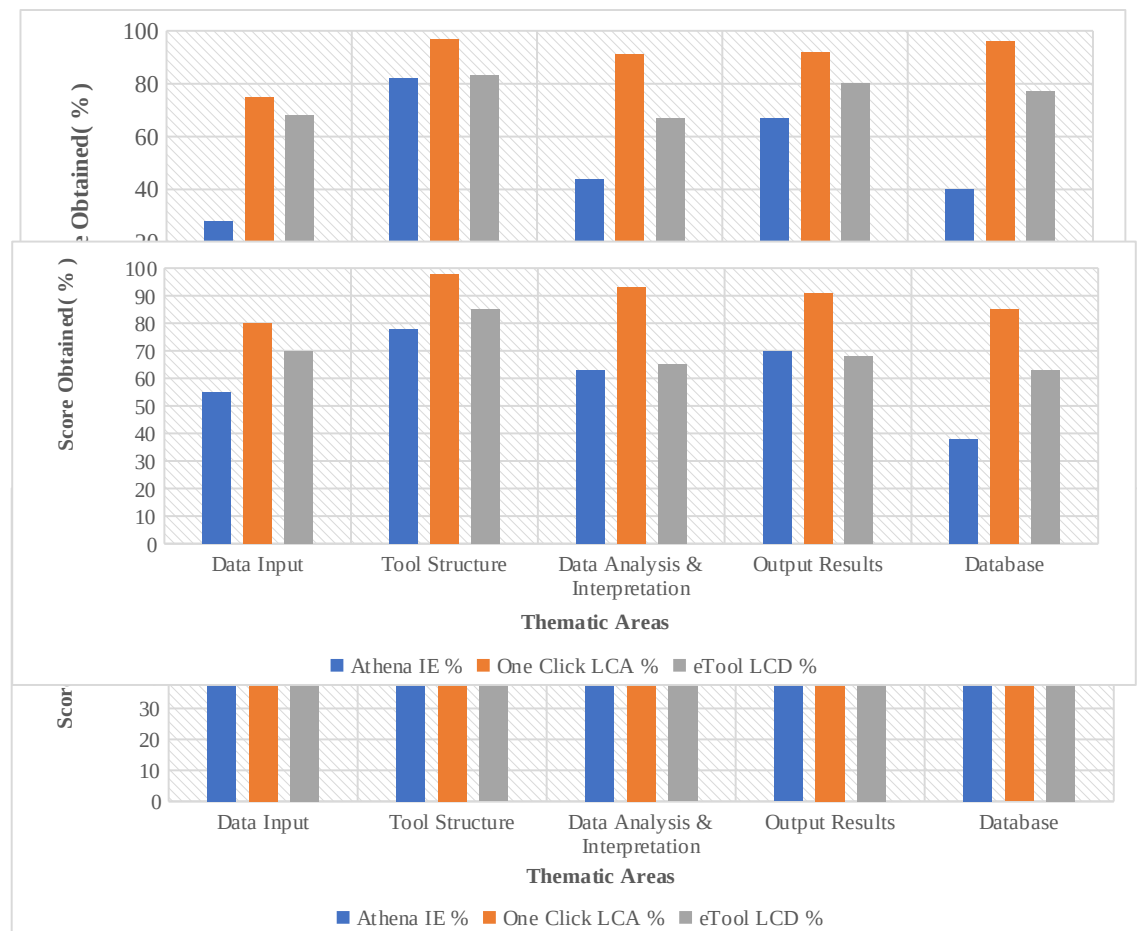


Figure 7: Comparison of tools based on contribution for sustainable design

Figure 8: Comparison of tools based on user-friendliness

In the aspect of Comprehensiveness of the software the availability of trial projects, the ability for users to select measurement units for materials, the availability of a large range of input materials in its database and the ability to add new materials to the database, and the possibility of linking building energy modeling software tools could be useful to improve the software tool based on comprehensiveness. When comparing the three LCA software tools, One Click LCA came out to be the best-performing tool, scoring more than 75% for each theme under each key attribute comprehensiveness of the LCA approach (Figure 6). The results show that data input, data analysis & interpretation, and database are three themes that scored the least when considering the tools Athena IE and eTool LCD. As per the results, the LCA software tools can be improved if more focus is given on the following themes: data input, data analysis & interpretation, and database. According to Figure 7, tool structure, data analysis & interpretation, and output results contribute strongly to making the designs more sustainable in all three tools. However, it was observed that the database and data input need further improvement. To do so, design comparison with sustainable materials can be implemented within the tool itself. When considering the key attribute user-friendliness as shown in Figure 8, the themes, data input, output results, and database have a strong contribution towards improving the user-friendliness in the tools One Click LCA and eTool LCD when compared with Athena IE. Athena IE has obtained comparatively fewer scores for all the five themes and out of the five themes, there is a drastic deviation observed in the theme database because Athena IE is weak as there is a lack of variety of

databases which causes a loss of wide range of materials within its database, also the geographical coverage given by Athena IE for materials is only concentrated for North America this in fact can also result in a low score. When considering the output results under user-friendliness, Athena IE has lower results because it only has a short range of graphical results interpretation methods.

4. Conclusion

This study aimed to compare the emissions of the three most built types of buildings in Sri Lanka using three different, widely used WBLCA tools: Athena IE, One Click LCA, and eTool LCD. The three tools were further assessed using attributes and thematic areas. Results showed approximately a 16% difference in the total carbon equivalent emissions obtained from the three tools, as the results are heavily impacted by the choice of materials, technical characteristics of the materials, different program inputs, assumptions made to carry out the analysis, and the different back-end calculations. For Building 1-office building, GWP values ranged from 13.4-22 kg CO₂-eq/m²/year. Building 2- apartment building showed more consistent GWP results (25.3-35.2 kg CO₂-eq/m²/year) but notable differences in the impacts of acidification (AP) and eutrophication (EP). Building 3 – residential building exhibited the lowest impacts overall, with GWP values between 9.7-12.6 kg CO₂-eq/m²/year. The study validated the existing finding that the highest contributor to GWP is the use stage (B1-B7), and the second highest contributor was the product stage (A1-A3). The tool comparison identified One Click LCA as the highest-scored tool, with 90% marks, whereas eTool LCD (75%) was ranked in second place and Athena IE (62%) was ranked in third place. This study is crucial for the construction industry as it advances progress toward sustainable development goals. The study has limitations, as it only focused on three buildings representing the three most significant types constructed in Sri Lanka in recent times. Further research should expand the sample size of the same building types and analyze additional building types using LCA tools, while also addressing the limitations of existing methodologies. This will enable the development of a more comprehensive approach aimed at reducing environmental impacts and supporting the achievement of SDGs.

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Author Contribution

All authors have equally contributed to this study and the paper.

Reference

- [1] S. Karunaratne and D. Dharmarathna, “A review of comprehensiveness, user-friendliness, and contribution for sustainable design of whole building environmental life cycle assessment software tools,” *Build. Environ.*, vol. 212, p. 108784, Mar. 2022, doi: 10.1016/j.buildenv.2022.108784.
- [2] A. Haapio and P. Viitaniemi, “A critical review of building environmental assessment tools,” *Environ. Impact Assess. Rev.*, vol. 28, no. 7, pp. 469–482, Oct. 2008, doi: 10.1016/j.eiar.2008.01.002.
- [3] E. Meex, G. Verbeeck, and P. Viitaniemi, “(PDF) User-friendliness of current building environmental impact assessment tools: an architect’s perspective,” in *ResearchGate*, Mar. 2016. Accessed: Jul. 16, 2025.

- [Online]. Available: https://www.researchgate.net/publication/299620623_User-friendliness_of_current_building_environmental_impact_assessment_tools_an_architect's_perspective
- [4] T. Bruce-Hyrkäs, P. Pasanen, and R. Castro, “Overview of Whole Building Life-Cycle Assessment for Green Building Certification and Ecodesign through Industry Surveys and Interviews,” *Procedia CIRP*, vol. 69, pp. 178–183, 2018, doi: 10.1016/j.procir.2017.11.127.
- [5] N. Emami *et al.*, “A Life Cycle Assessment of Two Residential Buildings Using Two Different LCA Database-Software Combinations: Recognizing Uniformities and Inconsistencies,” *Buildings*, vol. 9, no. 1, Art. no. 1, Jan. 2019, doi: 10.3390/buildings9010020.
- [6] T. Vasishta, M. Hashem Mehany, and J. Killingsworth, “Comparative life cycle assesment (LCA) and life cycle cost analysis (LCCA) of precast and cast-in-place buildings in United States,” *J. Build. Eng.*, vol. 67, p. 105921, May 2023, doi: 10.1016/j.jobee.2023.105921.
- [7] “Construction Industry Development Authority.” Accessed: Feb. 26, 2025. [Online]. Available: https://www.cida.gov.lk/index_e.php
- [8] Tudawe Brothers, “Tudawe Brothers - Construction Company - Sri Lanka.” Accessed: Jul. 19, 2025. [Online]. Available: <https://www.tudawe.com/>
- [9] “Maga Engineering (Pvt) Ltd. Sri Lanka |.” Accessed: Feb. 26, 2025. [Online]. Available: <https://www.maga.lk/>
- [10] International Construction Consortium (Pvt) Ltd, “ICC Construction.” Accessed: Jul. 16, 2025. [Online]. Available: <https://icc-construct.com/>
- [11] W. P. S. Dias, *USEFUL LIFE OF BUILDINGS*. 2003.
- [12] R. M. Bradley, “Forecasting Domestic Water Use in Rapidly Urbanizing Areas in Asia,” *J. Environ. Eng.*, vol. 130, no. 4, pp. 465–471, Apr. 2004, doi: 10.1061/(asce)0733-9372(2004)130:4(465).
- [13] British Standards Institution, “BS EN 15978:2011 | 30 Nov 2011 | BSI Knowledge.” Accessed: Jul. 21, 2025. [Online]. Available: <https://knowledge.bsigroup.com/products/sustainability-of-construction-works-assessment-of-environmental-performance-of-buildings-calculation-method>
- [14] L. F. Cabeza, L. Rincón, V. Vilariño, G. Pérez, and A. Castell, “Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review,” *Renew. Sustain. Energy Rev.*, vol. 29, pp. 394–416, 2014.
- [15] H. Monteiro and F. Freire, “Life-cycle assessment of a house with alternative exterior walls: Comparison of three impact assessment methods,” *Energy Build.*, vol. 47, pp. 572–583, Apr. 2012, doi: 10.1016/j.enbuild.2011.12.032.
- [16] P. Chopson, “Understanding LCA Standards: ISO 14040/14044 | cove.tool Help Center.” Accessed: Jul. 21, 2025. [Online]. Available: <https://help.covetool.com/en/articles/8814594-understanding-lca-standards-iso-14040-14044>

- [17] O. I. Olanrewaju, W. I. Enegbuma, M. Donn, and O. N. Oyefusi, “Assessment of environmental product declaration and databases: Towards ensuring data quality assurance practices,” *Environ. Impact Assess. Rev.*, vol. 112, p. 107803, Mar. 2025, doi: 10.1016/j.eiar.2024.107803.
- [18] Athena Sustainable Materials Institute, “IE for Buildings | Athena Sustainable Materials Institute.” Accessed: Jul. 21, 2025. [Online]. Available: <https://www.athenasmi.org/our-software-data/impact-estimator/>
- [19] S. Barbhuiya and B. B. Das, “Life Cycle Assessment of construction materials: Methodologies, applications and future directions for sustainable decision-making,” *Case Stud. Constr. Mater.*, vol. 19, p. e02326, Dec. 2023, doi: 10.1016/j.cscm.2023.e02326.
- [20] L. Chen, X. Gao, C. Hua, S. Gong, and A. Yue, “Evolutionary process of promoting green building technologies adoption in China: A perspective of government,” *J. Clean. Prod.*, vol. 279, p. 123607, Jan. 2021, doi: 10.1016/j.jclepro.2020.123607.
- [21] M. K. Dixit, J. L. Fernández-Solís, S. Lavy, and C. H. Culp, “Identification of parameters for embodied energy measurement: A literature review,” *Energy Build.*, vol. 42, no. 8, pp. 1238–1247, Aug. 2010, doi: 10.1016/j.enbuild.2010.02.016.
- [22] F. Pomponi and A. Moncaster, “Embodied carbon mitigation and reduction in the built environment – What does the evidence say?,” *J. Environ. Manage.*, vol. 181, pp. 687–700, Oct. 2016, doi: 10.1016/j.jenvman.2016.08.036.
- [23] I. Galiev and R. Ibragimov, “Determination of the time norms for excavating soil with a mini excavator,” *E3S Web Conf.*, vol. 258, p. 09044, 2021, doi: 10.1051/e3sconf/202125809044.
- [24] B. Sağlam and Ö. H. Bettemir, “Estimation of duration of earthwork with backhoe excavator by Monte Carlo Simulation,” *J. Constr. Eng. Manag. Innov.*, vol. 1, no. 2, pp. 85–94, Jun. 2018, doi: 10.31462/jcemi.2018.01085094.
- [25] Minister of Economic Affairs and Communications, “Methodology for calculating the energy performance of buildings–Riigi Teataja.” Accessed: Jul. 21, 2025. [Online]. Available: <https://www.riigiteataja.ee/en/eli/520102014002/>
- [26] US Department of Energy, “Water Efficiency in Federal Buildings and Campuses | Department of Energy.” Accessed: Jul. 21, 2025. [Online]. Available: <https://www.energy.gov/femp/water-efficiency-federal-buildings-and-campuses>

Annexures

Annexure 1: Specifics of the selected buildings

Building	Specifications		
Parameter	Building 1	Building 2	Building 3

	(Office Building)	(Apartment Building)	(Residential Building)
Number of Floors	07	06	03
Location	Colombo, Sri Lanka	Colombo, Sri Lanka	Colombo, Sri Lanka
Gross Floor area (m ²)	4934	5198.6	979
Total height (m)	21.0	18.3	7.9
Frame structure	Reinforced Concrete	Reinforced Concrete	Reinforced Concrete
Service life (years)	50	50	50
Foundation Type	Pad Footing	Pile Foundation	Strip Footing
Wall	Block masonry wall	Brick masonry wall	Brick masonry wall
Ceiling Type	Asbestos-free cement board ceiling	Aluminum framed grid ceiling with gypsum board	Gypsum Board Ceiling Work
Finishes	Non-slip porcelain tiles, ceramic tiles, cement lime & sand wall plaster	Non-slip ceramic tiles, porcelain tiles, cement render, cement sand wall plastering	Ceramic tile, cement render, cement sand wall plastering
Doors and Windows	Timber, Aluminum glass doors & windows	Timber, Aluminum framed glass doors & windows.	Timber glass doors & Windows

Annexure 2: Input data into the software

	LCA tool		
Data attribute	Athena IE	One Click LCA	eTool LCD
General Information of the Building,	- Floor area - Building height - Location of the building	- Floor area - Location of the building - Service life - Type of building	- Floor area - Location - Service life - Type of building

	• Service life • Type of building	• Certification required • Frame type	• Life cycle modules • indicators • Site attributes • Financial details
Energy consumption	Building annual operating energy consumption	Building annual operating energy consumption	Building annual operating energy consumption
Water consumption	-	Annual water consumption	Annual water consumption
Design details	-	-	Occupants, Lux
Building material source	BOQ	BOQ	BOQ
Construction site operation	-	yes	yes
Transportation	-	Transportation distances & modes of transport	Transportation distances & modes of transport

Annexure 3: Resources required as input parameters

Parameter	Data Source/ Reference	Actual Quantity Used
One Click LCA		
Materials required for the completion of earthworks, substructure, superstructure, internal and external finishes.	Obtained from BOQ	Same as from BOQ
Machinery usage data during the construction stage	[23], [24]	Site clearance = 8 hours (Backhoe) Soil Excavation = 30 hours (Excavator) Compaction = 20 hours (Compactor)
Operations during the construction stage	[25]	100000 kWh (B1) 100000 kWh (B2), 10000 kWh (B3)
- Electricity	[12], [26]	6000 m ³ (B1) 6000 m ³ (B2) 1000 m ³ (B3) -
- Water	-	-
- Fuel		
Operations during the operational stage	[25]	640100 kWh/year (B1), 560500 kWh/year (B2), 87900 kWh/year (B3)
- Electricity	[12], [26]	740 m ³ /year (B1) 10950 m ³ /year (B2) 740 m ³ /year (B3)
- Water		

Parameter	Data Source/ Reference	Actual Quantity Used
-	-	-
- Fuel		
Material replacement during maintenance	Automatically replaced by the software tool	As specified in the software tool
Chemicals, energy, and fuel required for the demolition/deconstruction stage	Automatically assigned by the software tool	As specified in the software tool
eTool LCD		
Materials required for the completion of earthworks, substructure, superstructure, internal and external finishes.	Obtained from BOQ	Same as from BOQ
Machinery usage data during the construction stage	Automatically replaced by the software tool	As specified in the software tool
Operations during the construction stage		
- Electricity	Automatically replaced by the software tool	As specified in the software tool
- Water		
- Fuel		
Operations during the operational stage	[25]	640100 kWh/year (B1), 560500 kWh/year (B2), 87900 kWh/year (B3)
- Electricity	[12], [26]	740 m ³ /year (B1)
		10950 m ³ /year (B2)
- Water		740 m ³ /year (B3)
	-	-

Parameter	Data Source/ Reference	Actual Quantity Used
- Fuel		
Material replacement during maintenance	Automatically replaced by the software tool	As specified in the software tool
Chemicals, energy, and fuel required for the demolition/deconstruction stage	Automatically assigned by the software tool	As specified in the software tool
Athena IE		
Materials required for the completion of earthworks, substructure, superstructure, internal and external finishes.	Obtained from BOQ	Same as from BOQ
Machinery usage data during the construction stage	Automatically replaced by the software tool	As specified in the software tool
Operations during the construction stage		
- Electricity	Automatically replaced by the software tool	As specified in the software tool
- Water		
- Fuel		
Operations during the operational stage	[25]	640100 kWh/year (B1), 560500 kWh/year (B2), 87900 kWh/year (B3)
- Electricity		
	Not considered by the tool	Not considered by the tool
- Water	-	-
- Fuel		
Material replacement during maintenance	Automatically replaced by the software tool	As specified in the software tool

Parameter	Data Source/ Reference	Actual Quantity Used
Chemicals, energy, and fuel required for the demolition/deconstruction stage	Automatically assigned by the software tool	As specified in the software tool