Construction Industries' LCA Adaptability: A Desk Study based SWOT Analysis

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Abstract

Life Cycle Assessment (LCA) is a method applied to enhance ecologically sustainable development in the construction industry. LCA is used extensively pertaining to the construction industry in developed counties rather than in developing countries. Accordingly, this study aimed to develop a literature-based SWOT analysis to examine the strengths and opportunities confronted by developed countries and weaknesses and threats faced by the developing countries in practicing LCA in the construction industry. The SWOT analysis is a data-driven, fact-based analysis used to overlooks internal and external factors to assist decision-making. Findings highlighted that developing Environmental Product Declarations (EPDs) for communication purposes in developed countries is the frequently claimed strength in implementing LCA. Lack of accurate LCA data in developing countries can be recognized as a highly reported weakness. Initiation of LCA software is the commonly stated opportunity to integrate LCA into the construction industry in developed countries. Lack of societies' environmental awareness has created the greatest threat to the application of LCA in developing nations. The study emphasized that developed countries enjoyed a literature-based multiplicity of strengths and opportunities whilst developing countries faced a great proportion of weaknesses and threats, which need to alleviate to create LCA enabled built environments in developing countries.

Keywords: Developed countries, Developing countries, Strengths/weaknesses, Threats/opportunities, Life Cycle Assessment

1. Introduction

The construction industry is a prominent contributor to both economic and social development in the contemporary world (Behm 2008). Nevertheless, the construction industry has also been identified as the main source of substantial environmental impact locally, nationally, and globally (Kylili et al. 2017). Evidently, the construction industry contributes immensely to the adverse global environmental impacts: for instance, the construction industry is responsible for approximately 40% of the energy consumption, 33% of the global GreenHouse Gas (GHG) emissions, 30% of raw material usage, 25% of solid waste generation, 25% of water consumption, and 12% of land use globally (Antón and Díaz 2014). Concurring with Xing et al.'s (2011) there is an indication that current building stock and other structures will be further escalated by 1% per year due to new constructions. It is probable that these environmental issues will become adverse along the timeline (Grundel and Dahlström 2016). Hence, there is an urgent requirement to mitigate these formidable environmental challenges that are arising from the construction industry activities (Sharma et al. 2011). Subsequently, different methods and tools have come into the practice to alleviate undesirable environmental problems, which can address the issues with a multi-disciplinary approach such as energy-saving, reduction of material usage, and emissions control etc. (Atmaca 2016).

Consequently, a number of environmental management tools have been implemented over the last decades to assess the environmental impacts of construction activities and to identify opportunities for environmental improvements (Manuilova et al. 2009). Examples include LCA, Strategic Environmental Assessment (SEA), Environmental Impact Assessment (EIA), Ecological Footprint etc. (Manuilova et al. 2009; Todd 2012). Amongst several environmental management tools, the LCA approach can be identified as a globally recognized method used to assess all environmental inputs (i.e. raw material, energy and water) and all environmental outputs (i.e. solid waste generation, atmospheric emissions, and waterborne waste) throughout the expected lifespan of the construction (Stevenson and

Ingwersen 2012). Moreover, the LCA approach is a prominent analytical tool and a methodical environmental management technique, which is utilized to holistically assess and analyze potential environmental impacts covering the product life cycle from its raw material extraction to final disposal (Bilec et al. 2009). Hence, LCA is often called a "cradle-to-grave" assessment method, as it considers and assesses all the possible environmental effects over the Whole Life Cycle (WLC) (Yarramsetty et al. 2018). As an attempt to organize and harmonize LCA applications, LCA was formalized by the International Organization for Standardisation (ISO) and the Society of Environmental Toxicology and Chemistry (SETAC) under the umbrella of the ISO 14000 series. This series is based on life cycle thinking with the aim of quantifying all environmental influences assignable to the product life cycle (Saunders et al. 2013). According to International Organization for Standardization [ISO] (2006), the implementation process of LCA is structured into four interlinked phases such as, (i) ISO 14041:1998 - Goal and Scope Definition, (ii) ISO 14041:1998 - Life Cycle Inventory (LCI), (iii) ISO 14042:2000 - Life Cycle Impact Assessment (LCIA), and (iv) 14043:2000 – Life Cycle Interpretation. Moreover, it can be identified that LCA has been utilized as a worldwide standardized procedure for environmental assessments (Bjørn et al. 2018) as it has been applied as a significant tool utilized for environmental management and sustainable construction all over the world (Crawford 2011). Consequently, LCA has been applied to evaluate the environmental performance of different construction outputs throughout WLC with the aim of reducing remarkable life cycle environmental impacts (Basbagill al. 2013).

Prevailing literature has witnessed a number of LCA applications in the construction industry, which support decision-making in the environmental sustainability context (Hauschild et al. 2017). LCA delivers a comprehensive panorama of potential environmental aspects of a building and creates a more precise picture of the exact environmental trade-offs by considering the WLC (Abd Rashid and Yusoff 2015). For example, according to the LCA study done by Carre (2011), the construction phase contributes to approximately 31-43% of GHG and 31-44% of Cumulative Energy Demand (CED) and when it comes to the operation phase it accounts to around 53–68% for GHG and 52–64% for CED, and maintenance accounts to around 4–6% of GHG and 5–6% for CED and the disposal phase only accounts for -1 to -5% for GHG and -1 to -3% for CED. With reference to studies carried out by Kutnar and Hill (2015), they pointed out that, LCA results are important in recognizing the 'hot-spots', which are the most significant environmental issues in the building life cycle, where improvements can be done to get the greatest environmental benefits. Moreover, as cited in Asif et al. (2007) it is highlighted that the materials used for the buildings are accountable for greater than 50% of the embodied energy in the building. In that sense, the utilization of alternative materials for instance; stabilized soil blocks, hollow concrete blocks, or fly-ashes, in place of the materials with a high embodied energy e.g. reinforced concrete is able to save approximately 20% of the cumulative energy used over a building life cycle (Huberman and Pearlmutter 2008). Likewise, LCA gives an overview of how different types of building materials contribute to adverse environmental impacts. Accordingly, LCA methodology helps in decision-making towards exploring more sustainable solutions. Therefore LCA can be identified as a tool for improving ecological sustainability within the construction industry (Ortiz-Rodríguez et al. 2010). Hence, it can be said that integration of LCA to the early design stage of building life cycle can bridge the gap between environmental challenges and socioeconomic development in the construction industry, by recognizing strategies for environmental improvement without the burden of shifting one life cycle phase to another (Asadollahfardi et al. 2015).

LCA has entered rapidly into developed countries with increased attention towards creating more environmental-friendly constructions (Guinee et al. 2010; Scheuer et al. 2003). Confirming the above view, LCA has been mostly engaged in the construction sector in developed countries like Europe, North America, Japan, and Korea (Islam et al. 2015). For example, Keoleian et al. (2000) conducted a study focusing on the building sector in the United States of America (USA). The results highlighted that the utilization phase of the building accounted for around 90% out of the total life cycle energy consumption. Aye et al. (2012) have conducted a similar study based on the Australian residential building sector, which is another example that can to be mentioned out of many reported studies. Supportively, prevailing literature indicates significant evidence of an extensive amount of building LCA being conducted in developed counties in comparison with the developing countries (Ortiz et al. 2009; Saunders et al. 2013). Compared to developed counties, developing countries have given less attention to implementing LCA within the construction industry. Also, the construction industry in developing countries has been in the position of high vulnerability to face environmental degradation, as a result of the booming nature of constructions, which drastically increases multi-facetted environmental and sociological challenges. This can be tackled and mitigated by integrating LCA into the construction industry in developing countries in making environmentally sound decisions.

The identified contradictory situation between developed countries and developing countries, emphasise the need to investigate as to why LCA has not been implemented in developing countries. Hence, this study in particular explores the strengths and opportunities confronted by developed countries and weaknesses and threats faced by the developing countries in implementing LCA for the construction industry by conducting a desk study. Thereafter, identified strengths and opportunities confronted by developed were suggested to achieve the weaknesses and threats faced by the developing countries in implementing LCA. Finally, last section discusse about the overall conclusion of the study.

2. Research Methodology

This paper adopts a desk study approach to locate strengths and opportunities confronted by developed countries and weaknesses and threats faced by the developing countries in implementing LCA for the construction industry. A desk study can be identified as a search of information using mainstream resources such as; published journal articles, published conference papers, analytical reports, books and other publications (Crisp 1981). In addition, a desk study can be recognized as a research method using secondary data, which is utilized to review the results of previous research outcomes for the purpose of obtaining a comprehensive understanding of the relevant research area (Bingham et al. 2012). The goals of the desk study were achieved by comprehensively evaluating published journal articles, books and other sources on problematic domains. This research has evaluated a total of 70 sources (1996–2018) containing 57 journal articles, 9 books and 4 unpublished doctoral dissertations from various databases including Springer, ScienceDirect, Emerald etc. were evaluated by covering developed and developing countries. Countries considered in the study present in Table 1.

Table 1: Developed and developing countries considered in the study

Developed Countries	Developing Countries
Belgium	Argentina
Germany	China
USA	Colombia
Netherlands	Greece
Israel	India
France	Iran
Hong Kong	Libya
United Kingdom (UK)	Malaysia
Australia	Sri Lanka
Canada	Turkey
Spain	
Sweden	

The tool used to capture strengths, opportunities, weaknesses, and threats faced by developed and developing countries is the SWOT analysis. Accordingly, researchers in the field of strategic management, utilize SWOT analysis which is an acronym for (Strengths, Weakness, Opportunities, and Threats) that is used to identify internal factors (i.e. strengths and weaknesses) and external factors (i.e. opportunities and threats), which are favorable and unfavorable to achieve specific objectives of the particular project or an activity (Zueva 2019). Supportively, Zlatanova and Isikdag (2009) developed a SWOT analysis to outline the strengths, weaknesses, opportunities and threats in the application of BIM (Building Information System) to the field of Architecture, Engineering, and Construction (AEC) industry. Moreover, SWOT analysis is used to reveal the external macro-environmental factors along with the internal country-specific forces in the course of implementing Building Energy Efficiency (BEE) in rural China (Zhang et al. 2018). Accordingly, based on the prevailing perspectives and utilization of SWOT analysis, it can be used to examine the current and emerging strengths and opportunities confronted by developed countries and weaknesses and threats faced by the developing countries in implementing LCA for the construction industry. When taking into consideration the LCA integration to the construction industry, the SWOT analysis which is data-driven, fact-based and which realistically overlooks internal and external factors will facilitate and assist with accurate decision-making for successful LCA integration. Hence, the designing of SWOT can be utilized as an effective tool as it constitutes suitable parameters to diagnose prevailing problems on LCA integration to the construction industry in the developing countries, whilst recommending actions to prevent forthcoming problems from both the internal and external environments. Accordingly, this study has developed the SWOT analysis to investigate strengths and opportunities confronted by developed countries and weaknesses and threats faced by the developing countries in implementing LCA for the construction industry.

3. Literature based SWOT Analysis and Discussion

The following sections focus on the detailed SWOT analysis for the purpose of identifying the strengths and opportunities confronted by developed countries and weaknesses and threats faced by the developing countries in implementing LCA to the construction industry. All strengths, opportunities, weakness and threats were formulated by considering the descending order of timescale of the literature source.

3.1. SWOT Analysis: Strengths

When developing the SWOT analysis for the LCA integration of the construction industry, the construction industry itself can be identified as the "internal environment". Favorable activities of the construction industry can be identified as "strengths". Moreover, strengths encourage and enable the application of LCA to the construction industry. Strengths, which have been reported by the prevailing literature can be explained as follows. Summary of the findings of the strengths is tabulated in Table 2 with relevant references and the reported time period.

Table 2: Strengths in integrating LCA for the construction industry in developed countries

No	Strengths	Reported Time Period	Ref. Code
S1	Concern on developing eco-labeling criteria and EPDs for communication purpose within the construction industry	2018-1996	[2],[3],[4], [6]
S2	Intention for identifying opportunities for ecological improvements in the construction industry	2015-1996	[3],[4], [6]
S3	Growing industrial interest to apply LCA to the construction industry	2015-2000	[1],[2]
S4	Positive growth in the construction industry to achieve environmental sustainability	2009	[6]
S5	Organization of workshops and forums on LCA to make people aware and educate about LCA	2009	[5]
S6	Highest interest in developing benchmarks for different building types	2009	[6]

Source: (Adapted from [1] Asadollahfardi et al. 2015; [2] Frankl and Rubik 2000; [3] Lewis and Demmers 1996; [4] McManus and Taylor 2018; [5] Dewulf 2009; [6] Zabalza Bribián et al. 2009)

According to Table 1, LCA integration to the construction industry in developed countries has been strengthened due to the increasing interest in identifying opportunities for ecological improvements over its life cycle and due to the considerable attention on reducing environmental impacts generated by the construction industry (Bilec et al. 2009). Dewulf et al. (2009) highlighted that the construction industry in developed countries actively participates in organizing workshops and publishing several handbooks (i.e. International Reference Life Cycle Data System Handbook (ILCD) on LCA, which can be identified as strengths in implementing LCA within the construction industry in developed countries. Further, there is an indication of the increasing importance of LCA between the years, 1996 to 2018 is the development of the novel concept called "Environmental Product Declarations" (EPDs) with respect to the construction industry (Frankl and Rubik 2000). An EPD can be identified as a set of calculated environmental data of a particular product with pre-defined parameter categories based on the LCA methodology or ISO 14040 series. Moreover, EPD makes it easy for designers to select eco-friendly materials or products for the construction (Fava 2006). Further, there is also an increasing interest in developing more and more green buildings in developed countries to achieve environmental sustainability since the year 2009 approximately. The erection of green buildings requires complete LCA to assess harmful environmental impacts during the entire building life cycle (Singh et al. 2011). Hence, the increasing interest in developing green buildings provides a strong foundation for the adoption of LCA within the construction industry in developed countries. Likewise, a number of studies have divulged various strengths that encourage the adoption of LCA to the construction sector in developed countries.

Moreover, findings highlighted that some sort of strengths have arisen since the year 2000 but quite a few new strengths (i.e. initiation of EPDs) have emerged in recent years, which encourage the adoption of LCA for the construction industry in developed countries. Accordingly, it is highlighted that strengths that are enjoyed by the developed countries enhance the ability of LCA application since last the decade. Hence, developing countries should make an effort to embed the above-identified strengths to its construction industry in order to facilitate a resourceful background to support the LCA application.

3.2 SWOT Analysis: Weaknesses

This section comprises of the weaknesses that the construction industry faces whilst attempting to implement LCA, for the purpose of reducing environmental impacts. From the SWOT's point of view, disadvantageous characteristics of the construction industry (internal environment) can be identified as "weaknesses". The summary of weaknesses from the literature findings is shown in Table 3 with its respective literature source and reported time period.

Table 3: Weaknesses in integrating LCA for the construction industry in developing countries

No	Weaknesses	Reported Time Period	Ref. code
W1	Deficiencies in collecting accurate and high-quality LCA data with respect to the construction industry	2015-2000	[3], [4], [8], [9], [11], [12], [13]
W2	LCA for the civil engineering structures are more complex than LCA for conventional products	2015-2007	[2], [4], [5], [15]
W3	Financial constraints in allocating funds to initiate LCA within the construction industry	2011- 2000	[6], [13], [14]
W4	The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)	2011-2000	[3], [7], [13], [14]
W5	Insufficient financial gains to the stakeholders compared with the costs of conducting LCA	2009	[16]
W6	Scarcity of adequate experienced professionals to perform LCA	2009-2000	[1], [3], [13]
W7	Confined stakeholder demand in performing LCA within the construction industry	2006	[10]
W8	Time taken time to conduct building LCA is long	2000	[7], [13]

Source: (Adapted from [1] Abeysundara et al. 2009; [2] Anastaselos et al. 2009; [3] Arena and Rosa 2003; [4] Chau et al. 2015; [5] Chau et al. 2007; [6] Electrical and Maniacal Service Department [EMSD] 2005; [7] Evans and Ross 2000; [8] Finnveden et al. 2009; [9] Haes 2002; [10] Hendrickson et al. 2006; [11] Jönsson 2000; [12] Katz 2010; [13] Lewis and Demmers 1996; [14] Malmqvist et al. 2011; [15] Mequignon et al. 2013; [16] Ng 2009)

According to Table 3, people are prejudiced to apply LCA during the years 2015 to 2007 due to the complexity of civil engineering structures in comparison to conventional products. In developing countries, it has been confirmed that a high proportion of LCA studies have addressed product development processes (i.e. paper production process and cement manufacturing process) rather than focusing on the construction sector. As per the explanation of Basbagill et al. (2013) compared to products manufactured in industries, civil engineering structures are unique in their nature, its lifetime is long and civil structures are complicated with multiple functions, hence the adoption of LCA to the areas of AEC industry have been restricted and it weakens the application of LCA to the construction industry in developing countries. Moreover, it was pointed out that there is a scarcity of LCA expertise to perform LCA studies in developing countries (Arena and Rosa 2003).

Jonker and Harmsen (2012) emphasized that a complete life cycle assessment generally requires months to complete even by a qualified and experienced LCA professional, as data collection consumes more time and resources. Unavailability of high-quality LCA databases in developing countries during the period, 2015 to 2000 has created a major practical bottleneck in LCA studies (Arena and Rosa 2003; Saghafi et al. 2011). Scheuer et al. (2003) interpreted that less LCA data on the upstream and downstream impacts of buildings limited the LCA application. Accordingly, far less information on regional specific LCA data, scarcity of professionals in the field of LCA, and high level of specialized knowledge needed by the complex LCA have weakened the LCA application to the construction industry in developing countries (Abeysundara et al. 2009). Hence, it has been emphasized that the application of LCA to the construction industry is more complex and expensive and also it limits the demand in applying LCA by stakeholders such as; contractors, consultants, architects and engineers (Hendrickson et. 2006).

Findings reveal that several weaknesses have been reported in the last decades. Also, some of the weaknesses are still prevailing over several years. Hence, developing countries should endeavor to minimize the above-identified weakness to implement LCA within its construction industry.

3.3 SWOT Analysis: Opportunities

"Opportunities" are the "external factors", which motivate the application of LCA to the construction industry. When considering the development of SWOT analysis for the construction industry LCA integration, external factors can arise due to the effects created by external parties such as government, civil society, environmental societies, and academia etc. Opportunities, which have been reported by prevailing literature can be explained as follows. The summary of the literature findings is depicted in Table 4.

Table 4: Opportunities in integrating LCA for the construction industry in developed countries

No	Opportunities	Reported Time Period	Ref. Code
O1	To obtain marketing benefits	2018	[4]
O2	Provision of tax reduction beficts for the reduction on environmental impacts	2108	[1]
O3	Empirically proved the benefits of conducting LCA	2018	[1]
O4	LCA as a novel approach for Research and Development	2015	[2]
O5	Due to the initiation of environmental policies which embeds LCA	2015- 1996	[2], [3]
O6	Development of LCA software packages developed for the construction industry	2015- 1996	[2], [3]
O7	Initiation of Simplified LCA method	2009	[5]
O8	Incorporation of LCA into green building certification processes	1996	[3]
O9	Favorable interest to initiate the green building implications	1996	[3]
O10	Integration of LCA with novel software such as Building Information Modeling (BIM)		

Source: (Adapted from [1] Amarasinghe 2018; [2] Asadollahfardi et al. 2015; [3] Lewis and Demmers 1996; [4] McManus and Taylor 2018; [5] Zabalza Bribián et al. 2009)

In line with the Table 4, most of the governments across the world promote and encourage the environmental assessments to predict possible environmental impacts through the whole value chain, since the year 1996. Subsequently, LCA has been widely embedded in the context of environmental regulations as a core element to take voluntary actions to build an ecologically sustainable construction industry in the US the European Union, Canada, Australia, Japan, Korea, and forthcoming booming economies such as India and currently China (Guinee et al. 2010), as LCA plays a leading role in promoting the principles of sustainable construction. Kögler and Goodchild (2017) reveal that government bodies promote and encourage the utilization of LCA by incorporating LCA into different policies and regulations such as Construction Products Regulation (CPR), European Commission on Integrated Product Policy (IPP), European standards for sustainable construction, and in the certification schemes for sustainable building constructions.

Furthermore, increasing awareness of environmental impacts generated by buildings, coupled with pressures from numerous stakeholders such as legislative bodies, government regulators, and environmental activist groups have been keen on introducing "the green building movement" in connection with the LCA since 1996 (Singh et al. 2011). Also, application of LCA provides a significant amount of credit in the green building certification processes such as Building Research Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED) version IV. Furthermore, the German Sustainable Building Council (DGNB), Green Building Initiative (GBI) and Green Globes rating system in the US can be identified as other programs that use LCA to analyze building life cycles whilst promoting LCA application within the construction industry. The purpose of LCA integration to the certification processes, standards and green building codes are to encourage professionals in the construction industry to compare and analyze different types of building materials and structural designs on the basis of its environmental impacts to make informed decisions during the building construction processes (Lewis and Demmers 1996).

When it comes to the perspective of academia, LCA is still becoming an active field for research. Hence, academics are interested in doing research-related activities on LCA with respect to the construction industry (Haes et al. 2004). Apart from that, Asadollahfardi et at. (2015) identified that environmental modeling software packages have recently been introduced as a collaborative activity of the academia and construction industry, which makes it easy to integrate LCA to the building sector. Szalay (2007) further elaborated that academia, government and construction industry are collaboratively involved in developing different LCA databases such as, ATHENA for US and Canada and GaBi and

SimaPro for Europe, which can be identified as opportunities in implanting LCA for developed countries. Additionally, Arena and De Rosa (2003), highlighted that the traditional LCA technique requires more data as well as time and resources to perform. Hence, a novel approach has been developed by stakeholders in academia and construction industry viz. "streamlined LCA" that requires fewer data to perform LCA. As well as academia, government and natural environment together initiate Institute for Environmental Research and Education (IERE) in America, in order to undertake and disseminate fact-based and comprehensive research on the area of LCA (Amarasinghe 2018). Not only that, but parties in the environment also play a prominent role in Europe and North America by promoting LCA through the United Nations Environmental Programme.

Accordingly, it can be noted that developed countries have taken advantage to implement LCA due to the number of different opportunities. Moreover, developed countries are enjoying benefits for the last several years, which reinforces the application of LCA in the construction area in developed countries. Hence, developing countries should also try to reap these benefits by embedding the abovementioned opportunities in their construction industry.

3.4 SWOT Analysis: Threats

Unfavorable "external factors" that may create the potential harm or limit the integration if LCA to the construction industry can be identified as "threats". Summary of literature findings regarding threats is shown in Table 5 with its respective literature source and reported time period.

Table 5: Threats in integrating LCA for the construction industry in developing countries

No	Threats	Reported Time Period	Ref. Code
T1	Limited availability of platforms to publicize the LCA concept	2018-2015	[1], [4]
T2	Absence of proper legislative initiatives and competent authorities to encourage the application of LCA	2016	[12], [2]
T3	Problems in credibility of LCA results	2013- 2009	[11], [13]
T4	Problems in understanding LCA results	2013-2012	[10], [11]
T5	Limited society awareness on LCA as a decision-making tool to assess building environmental performances	2013- 2001	[3], [8], [9], [10]
T6	Lack of favorable governmental incentives	2012- 1996	[7], [10], [13]
T7	The emergence of different types of environmental management tools	2010-2006	[5],[6]
T8	Non-integration of LCA with building management software	2009	[13]

Source: (Adapted from [1] Amarasignhe 2018; [2] Clark and De Leeuw 1999; [3] Electrical and Maniacal Service Department [EMSD] 2005; [4] Elkaseh et al. 2013; [5] Hendrickson et al. 2006; [6] Katz 2010; [7] Lewis and Demmers 1996; [8] Paulsen 2001; [9] Pour-Ghaz 2013; [10] Reed 2012; [11] Saunders et al. 2013; [12] Seidel 2016; [13] Zabalza Bribián et al. 2009)

According to the findings of Table 5, generally, a lack of societies' environmental awareness has created a threat to the application of LCA in developing nations, due to the deficiencies in current understanding about the concept and gaps between industry requirements and academic researches, since the year 2000 (Pour-Ghaz 2013). Furthermore, Amarasinghe (2018) stressed that lack of a platform to coordinate government authorities, LCA practitioners, environmentalists, scientists, and users, to share knowledge for the continuous improvement of LCA will threaten the spread of LCA within the construction sector in developing countries. Optimizing the environmental impacts of the construction industry is a must in the contemporary world. Despite common targets, national and international roadmaps related to the implementation of LCA, most of the developing countries experience obstacles when applying this knowledge practically due to the lack of integration of LCA with modern management software packages such as Building Information Molding (BIM) (Oviir 2016). Additionally, the lack of legislative governance measures in order to encourage building developers and designers to apply LCA in the early design stage barricades the application of LCA to the construction industry. Findings reveal that a number of threats have been reported for many years. Accordingly, it can be stated that in order to apply LCA within the construction industry in developing countries, threats that are reported through several years have to be minimized immediately to assist in implementing LCA.

The summary of the research findings is portrayed in Figure 1

Internal

'Strengths' of **developed countries**

S1. Concern on developing eco-labeling criteria and EPDs for communication purpose within the construction industry
S2. Intention for identifying opportunities for ecological improvements in the construction industry
S3. Growing industrial interest to apply LCA to the construction industry
S4. Positive growth in the construction industry to achieve environmental sustainability
S5. Organization of workshops and forums on LCA to make people aware and educate about LCA
S6. Highest interest in developing benchmarks for different building types

'Weaknesses' inherited by **developing countries** with **recommended actions** to **achieve 'Weaknesses'**

W1. Deficiencies in collecting accurate and high-quality LCA data with respect to the construction industry (**Recommended Actions to undertake - O5**)
W2. LCA for the civil engineering structures are more complex than LCA for conventional products (**Recommended Actions to undertake - O6 & S5**)
W3. Financial constraints in allocating funds to initiate LCA within the construction industry (**Recommended Actions to undertake - O2)**
W4. The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees) (**Recommended Actions to undertake - O6 & O7)**
W5. Insufficient financial gains to the stakeholders compared with the costs of conducting LCA (**Recommended Actions to undertake - O2)**
W6. Scarcity of adequate experienced professionals to perform LCA (**Recommended Actions to undertake - S5)**
W7. Confined stakeholder demand in performing LCA within the construction industry (**Recommended Actions to undertake - S5)**
W8. Time taken to conduct building LCA is long (**Recommended Actions to undertake - O6 & O7)**

External

'Opportunities' of **developed countries**

O1. To obtain marketing benefits
O2. Provision of tax reduction beficts for the reduction on environmental impacts
O3. Empirically proved the benefits of conducting LCA
O4. LCA as a novel approach for Research and Development
O5. Due to the initiation of environmental policies which embeds LCA
O6. Development of LCA software packages developed for the construction industry
O7. Initiation of Simplified LCA method
O8. Incorporation of LCA into green building certification processes
O9. Favorable interest to initiate the green building implications
O10. Integration of LCA with novel software such as Building Information Modeling (BIM)

'Threats' inherited by **developing countries** with **recommended actions** to **achieve 'Threats'**

T1. Limited availability of platforms to publicize the LCA concept (**Recommended Actions to undertake - S5**)
T2. Absence of proper legislative initiatives and competent authorities to encourage the application of LCA (**Recommended Actions to undertake - O5**)
T3. Problems in credibility of LCA results (**Recommended Actions to undertake - O6**)
T4. Problems in understanding LCA results (**Recommended Actions to undertake - O6**)
T5. Limited society awareness on LCA as a decision-making tool to assess building environmental performances (**Recommended Actions to undertake - O6**)
T6. Lack of favorable governmental incentives (**Recommended Actions to undertake – O2**)
T6. The emergence of different types of environmental management tools (**Recommended Actions to undertake – O2**)
T9. Non-integration of LCA with building management software (**Recommended Actions to undertake – O10**)

Figure 1: SWOT Analysis in integrating LCA into the construction industry

4. Research Findings

According to Figure 1, it can be highlighted that the developed countries partake of a vast majority of internal strengths as well as external opportunities. When considering the perspective of the developing countries, still they are in the position of facing a great number of internal weaknesses, as well as external threats for several years. Based on this study it is revealed that developing countries should try to minimize the internal weaknesses and external threats whilst appending internal strengths and external opportunities enjoyed by developed countries to enhance LCA application within the construction industry. Moreover, the findings of this study may be useful for developing countries to determine and implement mitigation mechanisms to alleviate identified weaknesses and threats faced by the developing countries in implementing LCA for the construction industry. Also, developing countries can take further actions to embed strengths and opportunities confronted by developed countries with the purpose of facilitating LCA enabled the construction industry in developing countries. Thereby, this research contributes to the growing international body of knowledge by recommending suitable mesures to achive internal weaknesses and external threats. Identified internal strengths and external opportunities can be used to mitigate and eliminate internal weaknesses and external threats as described in the Figure 1.

For example one of the weaknesses faced by the developing countries can be identified as 'deficiencies in collecting accurate and high-quality LCA data with respect to the construction industry' that can be eliminated by integrating the strength of 'development LCA databases and software packages specially for the construction industry'. Moreover, the research outcome would be highly significant to the stakeholders such as academia, government bodies, and environmentalists to identify their essential contribution towards the implantation of LCA to the construction industry in developing countries. Accordingly, it is proved that the developing countries have to perform particular activities in advance to implement LCA for the construction industry in developing countries.

5. Conclusions

LCA is a globally recognized structured method applied particularly to enhance ecologically sustainable development in the construction industry by assisting in the erection of environmentally-conscious buildings and other structures. Over the last decades, LCA has evolved significantly in developed countries (i.e. Europe, America and Australia), as a sophisticated assessment procedure used for eco-efficient designs, to strengthen the decision-making process in the built environment. Although the building LCA is well-rooted in developed countries, comparatively it is difficult to find shreds of evidence on LCA implementation in developing countries. The above-identified contradictory situation in developed countries vs. developing countries, emphasize the need for investigating as to why LCA has not been implemented in developing countries particularly, for reasons addressed throughout this study. The SWOT analysis was developed for the purpose of identifying the strengths and opportunities confronted by developed countries and weaknesses and threats faced by the developing countries in implementing LCA to the construction industry. Designing, SWOT can be utilized as an effective tool as it has constituted suitable parameters to diagnose prevailing problems on LCA integration to the construction industry in developing countries whilst helping to take action to prevent forthcoming problems posed by both the internal and external environments.

Findings highlight that out of six strategies, developing EPDs (Environmental Product Declaration) and eco-labeling criteria for communication purposes within the construction industry is the frequently claimed strength in implementing LCA in developed countries. Lack of accurate LCA data in developing countries can be recognized as a highly reported weakness. Initiation of LCA software packages is the commonly stated opportunity, which makes it easy to integrate LCA into the construction sector in developed countries. Lack of societies' environmental awareness has created the greatest threat to the application of LCA in developing nations, due to the deficiencies in the current understanding of the LCA concept. This study emphasized that developed countries enjoyed a multiplicity of strengths and opportunities whilst developing countries faced a great proportion of weaknesses and threats, which need to be alleviated to create LCA enabled built environments in developing countries.

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7. References

Abd Rashid, A. F., & Yusoff, S., A review of life cycle assessment method for building industry, *Renewable and Sustainable Energy Reviews*, vol. *45*, pp. 244-248, 2015.

Abeysundara, U. Y., Babel, S., & Gheewala, S., A matrix in life cycle perspective for selecting sustainable materials for buildings in Sri Lanka, *Building and Environment*, vol. *44* no. 5, pp. 997-1004, 2009.

Amarasinghe, S. D., *Comparative study on life cycle (LCA) assessment for buildings in Sri Lanka and developed countries* (Unpublished master's thesis), University of Moratuwa, Moratuwa, Sri Lanka, 2018.

Anastaselos, D., Giama, E., & Papadopoulos, A. M., An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions, *Energy and Buildings*, vol. *41*, no. 11, pp. 1165-1171, 2009.

Antón, L. A., & Díaz, J., Integration of LCA and BIM for sustainable construction, *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering*, vol. *8*, no. 5, pp. 1378-1382, 2014.

Arena, A., & De Rosa, C. (). Life cycle assessment of energy and environmental implications of the implementation of conservation technologies in school buildings in Mendoza—Argentina, *Building and Environment*, vol. *38,* no. 2, pp. 359-368, 2003.

Asadollahfardi, G., Asadi, M., & Karimi, S., Life-cycle assessment of construction in a developing country, *Environmental Quality Management*, vol. *24,* no. 4, pp. 11-21, 2015.

Asif, M., Muneer, T., & Kelley, R., Life cycle assessment: A case study of a dwelling home in Scotland, *Building and Environment*, vol. 42*,* no. 3, pp. 1391-1394, 2007.

Atmaca, A., Life cycle assessment and cost analysis of residential buildings in south east of Turkey: part 1—review and methodology, *The International Journal of Life Cycle Assessment*, vol. *21,* no.6, pp. 831-846, 2016.

Aye, L., Crawford, R. H., Gammampila, R., & Mendis, P., Life cycle greenhouse gas emissions and energy analysis of prefabricate reusable building modules. *Energy Build*, pp. 159–168, 2012.

Basbagill, J., Flager, F., Lepech, M., & Fischer, M., Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts, *Building and Environment*, vol. *60* pp 81-92, 2013.

Behm, M., Construction sector, *Journal of safety research*, vol. *39,* no. 2, pp. 175-178. 2008.

Bilec, M. M., Ries, R. J., & Matthews, H. S., Life-cycle assessment modeling of construction processes for buildings, *Journal of infrastructure systems*, vol. *16,* no. 3, pp. 199-205, 2009.

Bingham, I.J., Hoad, S.P., Lang, B., Philpott, H., Stobart, R., Thomas, J., Barnes, A.P., Ball, B.C., Knight, S. and Kightley, S., Desk study to evaluate contributory causes of the current yield plateau in wheat and oilseed rape, 2012.

Bjørn, A., Owsianiak, M., Laurent, A., Olsen, S. I., Corona, A., & Hauschild, M. Z., *Scope definition. In life cycle assessment* (pp. 75-116). Springer, Cham. 2018.

Buyle, M., Braet, J., & Audenaert, A., Life cycle assessment in the construction sector: A review, *Renewable and Sustainable Energy Reviews*, vol. *26*, pp. 379-388, 2013.

Carre, A., *A comparative life cycle assessment of alternative constructions of a typical Australian house design*. Melbourne, Australia: Forest and Wood Products, 2011.

Chau, C., Leung, T., & Ng, W., A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings, *Applied Energy*, vol. *143*, pp. 395-413, 2015.

Chau, C., Yik, F., Hui, W., Liu, H., & Yu, H., Environmental impacts of building materials and building services components for commercial buildings in Hong Kong, *Journal of Cleaner Production*, vol. *15,* no.18, pp. 1840-1851, 2007.

Clark, G., & De Leeuw, B., How to improve adoption of LCA, *The International Journal of Life Cycle Assessment*, vol. *4,* no. 4, pp. 184-187, 1999,

Crawford, R., *Life cycle assessment in the built environment*, London, England: Routledge, 2011.

Crisp, D.T., A Desk Study of the Relationship Between Temperature and Hatching Time for the Eggs of Five Species of Salmonid Fishes, *Freshwater Biology*, vol. 11, no. 4, pp. 361-368, 1981.

Dewulf, J., Van der Vorst, G., Versele, N., Janssens, A., & Van Langenhove, H., Quantification of the impact of the end-of-life scenario on the overall resource consumption for a dwelling house, *Resources, Conservation and Recycling*, vol. *53,* no. 4, pp. 231-236, 2009.

Electrical and Maniacal Service Department EMSD., *Life cycle assessment manual*, Available www.emsd.gov.hk/emsd/e_download/pee/Manual.pdf , May 20, 2005.

Elkaseh, T. A., Rahman, I. A., & Memon, A. H., Life cycle assessment in building projects of Libya: Barriers to implementation, *International Journal of Civil Engineering and Built Environment*, vol. *1,* no. 1, 2013.

Evans, D., & Ross, S., The role of life cycle assessment in Australia, *Australian Journal of Environmental Management*, vol. *5,* no. 3, pp. 137-145. 2000.

Fava, J. A., Will the next 10 Years be as productive in advancing life cycle approaches as the last 15 years? *The International Journal of Life Cycle Assessment*, vol. *11*, no. 1, pp. 6-8. 2006.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., & Suh, S., Recent developments in life cycle assessment, *Journal of Environmental Management*, vol. *91,* no. 1, pp. 1-21, 2009.

Frankl, P., & Rubik, F., Life cycle assesment in industry and business: Adoption patterns, applications and implications. *The International Journal of Life Cycle Assessment*, vol. *5,* no. 3, pp. 133-133, 2000.

Grundel, I., & Dahlström, M., A quadruple and quintuple helix approach to regional innovation systems in the transformation to a forestry-based bioeconomy, *Journal of the Knowledge Economy*, vol. *7,* no. 4, pp. 963-983, 2016.

Guinee, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Rydberg, T., Life cycle assessment: past, present, and future. 2010.

Haes, H. A., Heijungs, R., Suh, S., & Huppes, G., Three strategies to overcome the limitations of life-cycle assessment, *Journal of Industrial Ecology*, vol. *8* no. 3, pp. 19-32, 2004.

Haes, H. A., Jolliet, O., Norris, G., & Saur, K., UNEP/SETAC life cycle initiative: background, aims and scope, *The International Journal of Life Cycle Assessment*, vol. *7,* no. 4, pp. 192-195, 2002.

Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I., *Life Cycle Assessment: Theory and Practice*, Basingstoke, England: Springer. 2017.

Hendrickson, C. T., Lave, D. L., & Matthews, H. S., *Environmental life cycle assessment of goods and services: An input-output approach*. Resources for the Future, 2006.

Huberman, N., & Pearlmutter, D., A life-cycle energy analysis of building materials in the Negev desert, *Energy and Buildings*, vol. *40,* no. 5, pp. 837-848, 2008.

Islam, H., Jollands, M., & Setunge, S., Life cycle assessment and life cycle cost implication of residential buildings—A review, *Renewable and Sustainable Energy Reviews*, vol. *42*, pp. 129-140, 2015.

International Organization for Standardization. *Environmental management — Life cycle assessment — Life cycle interpretation*. Switzerland: ISO. 2006.

Jonker, G., & Harmsen, J., *Engineering for Sustainability: A Practical Guide for Sustainable Design*. Amsterdam, Netherlands: Elsevier. 2012.

Jönsson, A., Is it feasible to address indoor climate issues in LCA? *Environmental Impact Assessment Review*, vol. *20,* no. 2, pp. 241-259, 2000.

Katz, D., Life cycle costing for the planning, design, construction and operation of intelligent and green buildings. Available from http://www.slideshare.net/dkatz2/fed-lcc2010green-buildings, April 7, 2010.

Keoleian, G. A., Blanchard, S., & Reppe, P., Life cycle energy, costs, and strategies for improving a single family house, *Journal of Industrial Ecology*, vol. *4,* no. 2, pp. 135-156, 2000.

Kögler, K., & Goodchild, R., The European Commission's Communication 'Integrated Product Policy: Building on Environmental Life-Cycle Thinking'*, *Governance of Integrated Product Policy*, pp. 70-77, 2017.

Kutnar, A., & Hill, C., End of life scenarios and the carbon footprint of wood cladding, *In The carbon footprint handbook*, CRC Pres. 2015

Kylili, A., Ilic, M., & Fokaides, P. A., Whole-building life cycle assessment (LCA) of a passive house of the sub-tropical climatic zone, *Resources, Conservation and Recycling*, vol. *116*, pp. 169-177, 2017.

Lewis, H., & Demmers, M., Life cycle assessment and environmental management, *Australian Journal of Environmental Management*, vol. *3,* no. 2, pp. 110-123, 1996.

Malmqvist, T., Glaumann, M., Scarpellini, S., Zabalza, I., Aranda, A., Llera, E., & Díaz, S., Life cycle assessment in buildings: The ENSLIC simplified method and guidelines, *Energy*, vol. *36,* no. 4, pp. 1900-1907, 2011.

Manuilova, A., Suebsiri, J., & Wilson, M., Should life cycle assessment be part of the environmental impact assessment? Case study: EIA of CO2 capture and storage in Canada, *Energy Procedia*, vol. *1,* no. 1, pp. 4511-4518, 2009.

McManus, M. C., & Taylor, C. M., Greenhouse gas balances of bioenergy systems: The role of life cycle assessment, *Greenhouse Gases Balances of Bioenergy Systems*, pp. 29-41, 2018.

Mequignon, M., Adolphe, L., Thellier, F., & Ait Haddou, H., Impact of the lifespan of building external walls on greenhouse gas index, *Building and Environment*, vol. *59*, pp. 654-661. 2013.

Ng, E., *Designing high-density cities for social and environmental sustainability*. London, England: Earthscan. 2009.

Ortiz, O., Castells, F., & Sonnemann, G., Sustainability in the construction industry: A review of recent developments based on LCA, *Construction and Building Materials*, vol. *23,* no. 1, pp. 28-39, 2009.

Ortiz-Rodríguez, O., Castells, F., & Sonnemann, G., Life cycle assessment of two dwellings: One in Spain, a developed country, and one in Colombia, a country under development, *Science of the Total Environment*, vol. *408,* no. 12, pp. 2435-2443, 2010.

Oviir, A., Life cycle assessment (LCA) in the framework of the next generation Estonian building standard building certification as a strategy for enhancing sustainability, *Energy Procedia*, vol. *96*, pp. 351-362, 2016.

Paulsen, J., *Life Cycle Assessment for Building Products -The significance of the usage phase* (Unpublished doctoral dissertation, 2001.

Pour-Ghaz, M., Sustainable infrastructure materials: Challenges and opportunities, *International Journal of Applied Ceramic Technology*, vol. *10,* no.4, pp. 584-592, 2013

Reed, D., *Life-cycle Assessment in Government Policy in the United States* (Unpublished doctoral dissertation). University of Tennessee, 2012.

Saghafi, M. D., & Hosseini Teshnizi, Z. S., Recycling value of building materials in building assessment systems. *Energy and Buildings*, vol. *43,* no. 11, pp. 3181-3188, 2011.

Saunders, C. L., Landis, A. E., Mecca, L. P., Jones, A. K., Schaefer, L. A., & Bilec, M. M., Analyzing the practice of life cycle assessment: focus on the building sector, *Journal of Industrial Ecology*, vol. *17,* no. 5, pp. 777-788, 2013.

Scheuer, C., Keoleian, G. A., & Reppe, P., Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. *Energy and Buildings*, vol. *35,* no. 10, pp. 1049-1064, 2003.

Seidel, C., The application of life cycle assessment to public policy development. *The International Journal of Life Cycle Assessment*, vol. *21,* no. 3, pp. 337-348, 2016.

Sharma, A., Saxena, A., Sethi, M., & Shree, V., Life cycle assessment of buildings: a review, *Renewable and Sustainable Energy Reviews*, vol. *15,* no. 1, pp. 871-875, 2011.

Singh, A., Berghorn, G., Joshi, S., & Syal, M., Review of life-cycle assessment applications in building construction, *Journal of Architectural Engineering*, vol. *17,* no. 1, pp. 15-23, 2011.

Stevenson, M. J., & Ingwersen, W. W., Environmental product claims and life cycle assessment. *Life Cycle Assessment Handbook*, pp. 475-543, 2012.

Szalay, Z., *Life Cycle Environmental Impacts of Residential Buildings* (Unpublished doctoral dissertation), Budapest University of Technology and Economics, Hungary, 2007.

Todd, J. A., Buildings, systems thinking, and life cycle assessment. *Life Cycle Assessment Handbook*, pp. 311-328. 2012.

Xing, Y., Hewitt, N., & Griffiths, P., Zero carbon buildings refurbishment–A hierarchical pathway. *Renewable and Sustainable Energy Reviews*, vol. *15,* no. 6, pp. 3229-3236, 2011.

Yarramsetty, S., Sivakumar, M. V., & Raj, P. A., Recent developments in life cycle assessment and service life prediction: A review, *Urbanization Challenges in Emerging Economies*, 2018.

Zabalza Bribián, I., Aranda Usón, A., & Scarpellini, S. (). Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment*, vol. *44,* no. 12, pp. 2510-2520. 2009.

Zhang, L., Guo, S., Wu, Z., Alsaedi, A., & Hayat, T., SWOT analysis for the promotion of energy efficiency in rural buildings: A case study of china. *Energies*, vol. *11,* no. 4, 2018.

Zlatanova, S., & Isikdag, U., A SWOT analysis on the implementation of Building Information Models within the geospatial environment, *Urban and Regional Data Management*, 2009.

Zueva, O., SWOT-analysis as a method of strategic analysis and planning of safe innovative development of the real and financial sectors of the Russian economy, *Economics and Environmental Management*, pp. 163-170, 2019.

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