ENHANCING THE APPLICATION OF LIFE CYCLE ASSESSMENT IN THE CONSTRUCTION INDUSTRY: USE OF MODIFIED QUINTUPLE HELIX INNOVATION MODEL

Sedillage Don Isuri Anuradha Amarasinghe

(198056X)

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Department of Building Economics

University of Moratuwa

Sri Lanka

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ABSTRACT

Life Cycle Assessment (LCA) is identified as a systematic analytical tool used to assess the total environmental burdens related to any product, process, or activity by assessing all upstream flows and all downstream flows throughout the whole value chain. LCA has been applied significantly in developed countries, as a sophisticated assessment method to strengthen the decision-making process in the construction industry. Although LCA applications in the construction sector have been implemented comprehensively in the international arena, it is challenging to discover evidence in the Sri Lankan construction sector as a developing country. Also, the Sri Lankan construction industry has been in the position of highly vulnerable to face environmental degradation as a result of the booming nature of constructions, which drastically increases environmental challenges. Hence, it has become a key requirement for establishing LCA in the Sri Lankan construction industry as a solution to reduce the increasing adverse environmental impacts. Therefore, this study targets to bridge the research gap by solving the research problem of 'how to establish LCA practice in the construction industry through a Quintuple Helix Innovation approach?'. Literature findings emphasised the twelve (12) number of strengths and opportunities enjoyed by developed countries, which have improved the capacity of LCA applications. Further, literature findings indicate the eleven (11) number of weaknesses and threats faced by developing countries in establishing LCA. The qualitative research approach was adopted and an expert interview survey was used as the research method. Data was collected with the use of the Repertory Grid Interview (RGI) technique, and data collection was limited to twenty (20) expert interviews representing five (05) contenders in the Quintuple Helix Innovation Model. Data was analysed using manual content analysis. The empirical investigation highlighted that 'ability to identify opportunities for environmental improvements with the use of LCA' as one of the extremely important strengths identified by all contenders. 'Positive growth in the country to achieve environmental sustainability' identified as one of the extremely important opportunities by all contenders. 'Unavailability of experienced LCA professionals' identified as one of the weaknesses by all the contenders. 'Unavailability of accurate LCA data' categorized as one of the extremely influential threats by all the contenders. Then, individual SWOT analysis was developed for each of the contenders by identifying their respective strengths/opportunities and weaknesses/threats. Further, 'government intervention by providing financial incentives' and 'development of LCA database' are identified as some of the strategies to overcome the identified weaknesses and threats in establishing LCA for the construction industry. Finally, a Modified Quintuple Helix Innovation Model was developed and it could be employed to motivate all the related contenders to apply LCA as a decision-making tool to assess and mitigate environmental impacts generated by the Sri Lankan construction industry.

Keywords: *Academia, Construction Industry, Environmentalists, Government, Life Cycle Assessment, Quintuple Helix Innovation Model, Society*

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BIM	-	Building Information Modelling
CED	-	Cumulative Energy Demand
CPR	-	Construction Products Regulation
EPD	-	Environmental Product Declarations
ERA	-	Environmental Risk Assessment
GBCSL	-	Green Building Council of Sri Lanka
GHG	-	Green House Gas Emission
ISO	-	International Organization for Standardization
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventory
LCIA	-	Life Cycle Impact Assessment
MFA	-	Material Flow Analysis
MFA	-	Material Flow Analysis
RGI	-	Repertory Grid Interview
SCP	-	Sustainable Consumption and Production
UK	-	United Kingdom
USA	-	United States of America
WLC	-	Whole Life Cycle

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The construction industry symbolises principal and major assets (e.g., buildings and other infrastructure facilities) of any country's national economy, as it contributes to satisfying human, physical, economic, and social desires in the contemporary world (Hovde & Moser, 2004; Newton, Hampson, & Drogemuller, 2009; Ofori, 2012). Nevertheless, the construction industry is constantly cited as one of the prime promoters of environmental impairment locally, nationally, and globally (Aktas & Bilec, 2011; Kylili, Ilic, & Fokaides, 2017). The construction industry creates an enormous impact on the global environment: for instance, it is constituting 40% of the world total energy demand, approximately 33% of the total Global Greenhouse Gas (GHG) emissions, 30% of total material usage, roughly 25% of solid waste generation, 25% of water consumption and 12% of land use globally per year (Aktas & Bilec, 2011; Antón & Díaz, 2014). This environmental burden is going to be further exacerbated as the world population has continued to expand, requiring more buildings and infrastructure facilities for the community to live and work comfortably (Robertson, Lam, & Cole, 2012).

For improving the environmental performance of the constructions industry, ecological considerations such as energy-saving, reduction of material usage, and emissions control are required to be amalgamated into the decisions made by a variety of stakeholders in the construction industry (Eckerberg & Nilsson, 2013; Haapio & Viitaniemi, 2008; Weißenberger, Jensch, & Lang, 2014). With the arousing eco-consciousness, plenty of environmental management tools have been introduced to making more environmentally-sound decisions by taking above mentioned ecological considerations into account (Finnveden & Moberg, 2005; Nicoletti, Notarnicola, & Tassielli, 2002). Examples include Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA), Cost-Benefit Analysis (CBA), Environmental Risk Assessment (ERA), Ecological Footprint, Material Flow Analysis

(MFA), etc. (Buyle et al., 2013; Finnveden et al., 2009; Manuilova, Suebsiri, & Wilson, 2009).

Amongst, tools mentioned above, LCA could be identified as a systematic analytical tool used to assess the total environmental burdens related with any product, process, or activity by recognising and calculating all the environmental inputs (e.g., raw material, energy, and water) and environmental outputs (e.g., solid waste generation, atmospheric emissions, and waterborne waste) throughout the whole value chain (Chau, Leung, & Ng, 2015). Moreover, the LCA approach is an analytical decision support tool, which is utilised to holistically assess and analyse potential environmental impacts covering the entire lifecycle encompassing material extraction, processing, transportation, construction, operation, maintenance, repair, replacement, recycling, and final demolition (Bilec, Ries, & Matthews, 2009). Hence, LCA is often called a “cradle-to-grave” assessment method, as it considers and assesses the possible environmental effects over the Whole Life Cycle (WLC) of a construction (Ehtiwesh, Coelho, & Sousa, 2016; Yarramsetty, Sivakumar, & Raj, 2018).

Literature has witnessed several LCA applications in the construction industry, which support in making environmental-friendly decisions (Hauschild, Rosenbaum, & Olsen, 2017). For example, according to the study conducted by Carre (2011), the building construction phase contributes approximately 31-43% of GHG and 31-44% of Cumulative Energy Demand (CED). The operation phase accounts for around 53–68% for GHG and 52–64% for CED. Further, building maintenance activities account for 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. Likewise, LCA gives an overview of environmental impacts generated over the WLC. Accordingly, LCA could be used as a decision-making tool when planning construction activities to limit environmental impacts (Ortiz-Rodríguez, Castells, & Sonnemann, 2010).

On the other hand, LCA has been mostly applied in the construction sector in developed countries like Europe, North America, Japan, and Korea (Islam, Jollands, & Setunge, 2015). For example, Keoleian, Blanchard and Reppe (2000) conducted the LCA by focusing on the building sector in the United States of America (USA). Aye, Crawford, Gammampila, and Mendis (2012) studied by considering the Australian residential building sector. Several studies have divulged various positive factors that encourage the adoption of LCA to the construction industry in developed countries, Dewulf, Van der Vorst, Versele, Janssens, and Van Langenhove (2009) highlighted that academics, government, and environmentalists actively participate in organising workshops, publishing scientific papers and several handbooks (e.g., International Reference Life Cycle Data System Handbook (ILCD)) on LCA. On the other hand, existing literature illustrates significant evidence on negative factors faced by developing countries in establishing LCA into the construction industry such as lack of regional specific LCA data, scarcity of professionals in the field of LCA, and high level of specialised knowledge needed by the complex LCA (Ardente, Beccali, Cellura, & Mistretta, 2008; Ding, 2014).

According to the identified positive factors acquired by developed countries, LCA establishment in the construction industry needs to be dealt in collaboration with the essential stakeholders such as academia, environmentalists, environmental managers, investors, architects, government, regulatory agencies, the general public, policymakers, designers, contractors, and engineers. Hence, the LCA establishment in the construction industry could be identified as a collaborative innovation development process rather than a simple activity. In the search for innovative ways to cope the establishment of LCA in the construction industry, several types of innovation models could be identified such as Mode 1, Mode 2, Mode 3, Triple Helix, Quadruple Helix, and Quintuple Helix (Carayannis, Grigoroudis, Campbell, Meissner, & Stamati, 2017).

According to the literature, it could be determined that the appropriate model for analysing this complex and collaborative innovation introduced by the LCA into the construction industry is the "Quintuple Helix Innovation Model" because it produces a synergy between academia, government, construction industry, society and environmentalists (Baccarne, Logghe, Schuurman, & De Marez, 2016). According to Carayannis, Barth, and Campbell (2012), the Quintuple Helix Innovation Model comprises five (05) contenders: the (01) academia, (02) the government, (03) the construction industry, (04) the society, and (05) the environmentalists. Other types of innovations models (e.g., Mode 1, Mode 2, Mode 3, Triple Helix, and Quadruple Helix) do not focus on all the stakeholder categories. Moreover, essential stakeholders in the process of LCA establishment in the construction industry could be aligned with the Quintuple Helix Innovation Model significant five (05) contenders. Therefore, the Quintuple Helix Innovation Model identified as the most appropriate model to analyse the establishment of LCA to the construction industry than other aforesaid traditional approaches. Accordingly, there is an urgent need for identifying the role of relevant contenders (e.g., academia, industry, government, society, and environmentalists) in the Quintuple Helix Innovation Model for establishing LCA in the construction industry.

1.2 Problem Statement

LCA applications in the construction sector have been implemented comprehensively in the international arena, it is challenging to discover evidence in the construction sector of Sri Lanka (Ariyarathna, Siriwardhana, & Danthurebandara, 2016; Ramachandra & Karunasena, 2017). Dissanayake (2016) has revealed that with the process of speedy urbanisation, the Sri Lankan construction industry contributes to approximately 50% of energy usage, 40% of raw material use, 40% of GHG emissions, and 30% of waste generation annually. Further, the booming nature of the Sri Lankan construction industry drastically increases multi-facetted environmental challenges (Munasinghe, Deraniyagala, Dassanayake, & Karunarathna, 2017), which could be solved and mitigated by the establishing LCA in the Sri Lankan construction industry. Therefore, establishing LCA in the construction sector remains a domain of discovery and innovation, which has become a privileged space to create new knowledge to embrace the concept of LCA in the Sri Lankan construction industry.

Therefore, appropriate research would be beneficial to modify the original Quintuple Helix Innovation Model, explicating the significant contender roles for establishing LCA in the construction industry. This has prevailed as a vital and worthy researchable area in the current context, with only a few research studies having been conducted in the background of specified concern. Therefore, this study targets to bridge the research gap by solving the research problem of 'how to establish LCA practice in the Sri Lankan construction industry through a Quintuple Helix Innovation Model?'

1.3 Aim and Objectives

This research aims to investigate how to enhance LCA application in the construction industry using the Quintuple Helix Innovation approach.

In order to achieve the above aim, the following objectives are developed.

1. Critically review the factors influencing on LCA application in the construction industry with reference to the essential stakeholders
2. Propose the essential contextual stakeholders for establishing LCA in the construction industry aligned with the Quintuple Helix Innovation Model significant contenders
3. Evaluate the strengths/opportunities and weaknesses/threats for establishing LCA in the construction industry in internal vs. external perspectives to develop individual SWOT analyses
4. Develop a modified Quintuple Helix Innovation Model integrating the significant contender roles and strategies for establishing LCA in the construction industry

1.4 Research Methodology

Initially, an exhaustive literature review was conducted to critically review the factors influencing on LCA application in the construction industry. Then, the literature synthesis explored the positive factors faced by developed countries and the negative factors faced by developing countries for establishing LCA in the construction industry. Moreover, positive factors and negative factors were identified concerning the relevant stakeholders.

After that, the identified contextual stakeholders for establishing LCA in the construction industry were aligned with the contenders of the Quintuple Helix Innovation Model.

A Qualitative research approach was adopted for the study, as it is the most suitable approach to achieve the aim of the research, where it urges for a high amount of qualitative data. An expert survey was selected as the research method. Data collection was done with the use of the repertory grid interviewing technique. Interviews were conducted with experts in the fields of LCA, and environmental sustainability representing all the contenders as identified in the innovation model. Expert interviews were employed to evaluate the positive factors and negative factors for establishing LCA in the construction industry in internal vs. external perspectives. Ultimately, analysis of repertory grid data was used to create SWOT analyses for each contender. Finally, the modified Quintuple Helix Innovation Model was developed, integrating the significant contender roles and strategies for establishing LCA in the construction industry.

1.5 Scope and Limitations

In several other industries where LCA applications exist, the current research is based on the cradle to grave LCA application in the construction industry. The booming nature of the construction industry in Sri Lanka has greatly increased the environmental challenge, which could be resolved and mitigated by establishing LCA in the construction industry to make environmentally sound decisions, in a timely manner. LCA was introduced in Sri Lanka at the end of the 2000s, although it has been used recently and very limitedly in the construction industry in Sri Lanka. Therefore, it is difficult to find experienced professionals in the research field. Consequently, data collection was limited to twenty (20) expert interviews representing academics, government organisations, construction companies, society (NGOs and non-profit organizations), and environmentalists. Four (04) expert interviews were conducted under each contender. ‘Experts’ refer to people who have extensive and in-depth capabilities in terms of knowledge, skills, and experience through practice and education in specific fields (Nonaka, 2006). Data collection was done up to the data saturation point.

1.6 Chapter Breakdown

The structure of this research study in chapters is explained below.

- **Chapter 1 – Introduction**

Given the brief introduction to the research with a background study, aim, objectives, methodology, and scope and limitations of the research.

- **Chapter 2 – Literature Review**

Present a comprehensive literature synthesis on the significance of LCA application in the construction industry. Then, explore the positive factors and negative factors for establishing LCA in the construction industry with the relevant stakeholders. The identified contextual stakeholders for establishing LCA in the construction industry were aligned with the contenders for the Quintuple Helix Innovation Model.

- **Chapter 3 - Research Methodology**

Present a research methodology. This research adopted a qualitative approach and conducted an expert interview survey with the use of the repertory grid interviewing technique. Content analysis was used as a data analysis technique.

- **Chapter 4 –Data Collection, Analysis, Research Findings, and Discussion**

Present the results of the positive and negative factors faced by the five (05) contenders in the innovation model by after evaluating their internal perspectives versus external perspectives. Research results were then obtained to develop a SWOT analysis for five (05) contenders. Further, the strategies were proposed to overcome weaknesses and threats faced five (05) contenders for establishing LCA in the Sri Lankan construction industry. Finally, the modified Quintuple Helix Innovation Model was developed by abstracting individual SWOTs to demonstrate the modified roles of contenders for establishing LCA in the Sri Lankan construction industry.

- **Chapter 5 – Conclusions and Recommendations**

Discusses the overview and conclusions of the research results and describes the contribution of this research to existing knowledge with recommendations to establish LCA in the Sri Lankan construction industry.

1.7 Chapter Summary

The background study, the research problem, the aim and objectives, the scope and limitations of the research are presented exhaustively in this chapter. Besides, the research methodology, which was adopted to achieve the research aim and objectives, is discussed briefly. A chapter breakdown of the research is described, highlighting the contribution of each chapter to the accomplishment of the research objectives.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Chapter two illustrates an extensive review of the literature to explore the current theoretical status of the research area. First, the LCA approach had been reviewed by highlighting the significance of LCA application in the construction industry. Then, factors influencing on LCA application in the construction industry with reference to the essential stakeholders are explored. The next phase of the literature review was centralised to hypothesise the best model to establish LCA to the construction industry as the Quintuple Helix Innovation Model while taking into account other types of innovation models. Simultaneously, existing Quintuple Helix Innovation Models, which were developed for different other purposes, were reviewed to form the theoretical base to develop a modified Quintuple Helix Innovation Model for establishing LCA in the Sri Lankan construction industry.

2.2 Life Cycle Assessment: A Tool for Assessing Environmental Impacts

LCA is alternatively known as “eco-balance,” “lifecycle analysis,” and “cradle-to-grave” analysis (Roy Choudhury, 2014). It is a process, which focuses on assessing the total ecological burdens related with any product, process, or activity by recognising and calculating all environmental inputs (e.g., raw material, energy, and water) and environmental outputs (e.g., solid waste generation, atmospheric emissions, and waterborne waste) over the entire lifecycle (Chau, Leung, & Ng, 2015; Ribeiro, Peças, Silva, & Henriques, 2008). Moreover, the LCA approach is a prominent analytical tool and a methodical environmental management technique, which is utilised to holistically assess and analyse potential environmental impacts covering the product life cycle from raw material extraction to final disposal (Bilec, Ries, & Matthews, 2009). Hence, LCA is often called a “cradle-to-grave” assessment method, as it considers and assesses the possible environmental effects over the WLC (Adamczyk & Dzikuć, 2014; Cabeza et al., 2014; Ehtiwesh, Coelho, & Sousa, 2016; Yarramsetty, Sivakumar, & Raj, 2018).

Atmaca (2016) affirmed that the term “cradle-to-grave” refers to the cumulative environmental impacts, which are initiated with the extraction of raw materials from the earth and, and ends up at the point, where all residuals go back again to the earth.

As an attempt to organise and harmonise LCA applications, LCA was formalised by the International Organisation for Standardisation (ISO) under the umbrella of the ISO 14000 series, which is based on lifecycle thinking to quantify all environmental influences assignable to product lifecycle (Saunders et al., 2013). The implementation process of LCA is structured into four (04) 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.

2.2.1 Significance of LCA Application in the Construction Industry

Environmental improvement in the construction industry would be pivotal for the community’s ecological sustainability development (Kulczycka et al., 2011). LCA could be identified as an appropriate and supportive scientific approach which consider and assess all upstream flows (e.g., raw material extraction, raw material production, material transportation, building construction and usage), and all downstream flows (e.g., deconstruction and final disposal of the building) over the WLC (Hendrickson, Lave, & Matthews, 2006; Kofoworola & Gheewala, 2008; Scheuer, Keoleian, & Reppe, 2003). Hence, LCA has been used to characterised an eco-profile of constructions through the assessment of inputs and outputs (Corrie, 2018). Therefore, LCA could be applied for predicting the way that the buildings and other civil engineering structures perform over their lifespan (Basbagill, Flager, Lepech, & Fischer, 2013). Accordingly, as quoted by Jolliet et al. (2004), LCA is applied to enhance ecologically sustainable development in the construction industry by assisting in erecting environmentally-conscious constructions (e.g., buildings, infrastructure facilities, etc.). As Elkaseh, Rahman, and Memon (2013) distinguished, LCA examines hidden costs items, which are not normally reflected through the conventional assessment methods. Hence, stakeholders in the construction industry (e.g., contractors, consultants, engineers, government bodies, the general public, environmentalists, etc.) have used LCA to implement decisions by considering the overall environmental benefits rather than the initial cost (Han, Srebric, & Enache-Pommer, 2014).

2.2.2 LCA Applications in the Construction Industry

LCA allows decision-makers to prioritise, optimisation efforts based on accurate information, therefore, LCA is driven to the construction sector by integrating proactive environmental concerns such as; optimise resource usage, energy consumption, and waste generation over the lifecycle (Zhang, Provis, Reid, & Wang, 2014). Then, LCA results could be used to compare the environmental impacts of alternative materials that could be used during the construction process to select materials with the least environmental impacts. For example, LCA conducted by Asif, Muneer, and Kelley (2007) 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 utilisation of alternative materials for instance; stabilised soil blocks, hollow concrete blocks, or fly-ashes, in place of the materials with a high embodied energy (e.g., reinforced concrete) could save approximately 20% of the cumulative energy used over a building life cycle (Huberman & Pearlmutter, 2008). Apart from that, another LCA study reveals that recycling building materials are vital to reduce the embodied energy in the buildings (Blengini, 2009; Thormark, 2002). For example, the use of recycled Aluminum and Steel confers savings of more than 50% in embodied energy (Chen, Burnett, & Chau, 2001).

Moreover, LCA provides an overview of in what way the different structural components (e.g., walls, foundations, floors, roof, slabs, etc.) contribute to the total environmental impacts. Hence, LCA results help when determining which structural component needs to be highly considered to limit the probable environmental influences generated from the constructions (Notarnicola et al., 2017; Ortiz-Rodríguez, Castells, & Sonnemann, 2010). Moreover, LCA assists decision-makers to select technologies that are least burdensome to nature to enhance environmental stability (Guinee et al., 2010). Apart from this, Kutnar and Hill (2015) pointed out that one of the valuable outcomes of the LCA study is to recognise the ‘hot-spots,’ which are the most significant environmental issues in the lifecycle, where the improvements could be made to get the greatest environmental benefits. As, LCA considers a wide range of environmental impacts categories such as global warming, resource depletion, land transformation, and use, water depletion, eutrophication, ozone depletion, acidification, eco-toxicity, photochemical smog formulation, respiratory effects, etc. (Rebitzer et al., 2004). Accordingly, LCA methodology helps in decision making towards exploring more sustainable solutions. Therefore, LCA could be identified as a tool for improving ecological sustainability within the construction industry (Ortiz-Rodríguez, Castells, & Sonnemann, 2010). Hence it could be emphasised that incorporation of LCA to the early design stage of construction would reinforce to make environmentally-conscious decisions with proper scientific justification. Therefore, LCA has recently emerged as a decision support technique in the areas of the construction industry in a coherent way (Monteiro & Freire 2012; Ramesh, Prakash, & Shukla, 2010; Rodrigues & Freire, 2014; Sartori & Hestnes, 2007; Sharma et al., 2011).

2.2.3 The Status of LCA Application in the Construction Industry of Developed and Developing countries

LCA seems to be utilised rapidly in developed countries with increased attention towards creating more environmental-friendly constructions (Guinee et al., 2010; Huang, Liu, Krigsvoll, & Johansen, 2018; Islam, Jollands, & Setunge, 2015; Scheuer, Keoleian, & Reppe, 2003). Confirming the above view, LCA has been mostly engaged in the construction sector in industrialised countries such as; Europe, North America, Japan, and Korea (Society of Environmental Toxicology and Chemistry [SETC], 2005). Supportively, the literature indicates that there is evidence that a large number of LCA have been carried out in developed countries rather than developing countries in the construction industry (Saunders et al., 2013). For example, Keoleian, Blanchard and Reppe (2000) conducted LCA in the US construction sector. The results show that the use phase of the building accounts for about 90% of the energy consumption. Besides, Aye et al. (2012) LCA was conducted LCA by considering the Australian residential construction sector. An 8-story 3943-square-meter multi-story residential building was examined. The results of the study concluded that the use of prefabricated steel structures could reduce material usage by 78% compared to conventional concrete structures. However, the study pointed out that compared with traditional concrete buildings, the embodied energy consumption of prefabricated steel structures has increased significantly (about 50%). Overall it could be stated that the reuse of materials used in the prefabricated steel building denotes 81% saving, in embodied energy consumption and 51% of materials are saving by mass. Accordingly, it was proved that LCA is not a novel concept in developed countries (Edirisinghe, 2013). Conferring that Basbagill et al. (2013) stated that the application of LCA to developing countries would be limited due to several reasons (e.g., lack of funding to implement LCA in the construction industry, lack of specialised LCA professionals, etc.).

2.3 Factors Influencing the LCA Application in the Construction Industry

The above-identified contradictory situation between developed countries and developing countries have emphasised the need for investigating why LCA has not been established in developing countries. Hence, it is very critical to identify the factors that positively or negatively affect the LCA establishment. Hence, the following sections focus on identifying positive and negative factors towards establishing LCA in the construction industry while identifying relevant stakeholders.

2.3.1 Positive Factors Influencing on LCA Application in the Construction Industry

This section presents the positive factors in the construction industry when adopting LCA. Several studies highlighted various positive factors faced by different stakeholders for establishing LCA in the construction industry. The summary of the literature findings of the positive factors with relevant stakeholders is presented in Table 2.1.

Table 2.1: Positive Factors Faced by Different Stakeholders for Establishing LCA in the Construction Industry

No	Positive Factors	Relevant Stakeholder	Ref. Code
I.	Ability to identify opportunities for environmental improvements with the use of LCA	Engineers, Designers, Planners Academia, Environmental authorities, Government, Non-Governmental Organizations (NGO)	4, 7
II.	Ability to develop benchmarks for different building types with the use of LCA	Engineers, Academia, Government Environmental authorities,	7
III.	To develop eco-labeling criteria and EPDs for communication purposes	Engineers, Academia, Government Environmental authorities	3,3,5, 7
IV.	Positive growth in the country to achieve environmental sustainability	Designers, Planners, Investors, NGO Contractors, Academia, Government, Environmental authorities	7
V.	The ability to use LCA as a novel approach for Research and Development (R&D)	Academia, Environmental authorities, Government	2
VI.	Initiation of environmental policies which incorporate LCA	Environmental authorities, Government	2,4
VII.	Ability to obtain marketing benefits	Investors, Government	4, 5
VIII.	Empirically proved benefits of conducting LCA	Academia, Government Environmental Authorities, NGO	1
IX.	The availability of LCA software packages to easily perform the LCA	Engineers, Designers Planners Academia, NGO Environmental authorities, Government	2, 3
X.	The availability of standardise LCA guides and handbooks	Engineers, Designers Planners Academia, Government Environmental authorities, NGO	7
XI.	Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA	Engineers, Designers Planners Academia, Engineers, Government Environmental authorities, NGO	1, 4
XII.	Use of Building Information Modeling (BIM) with LCA tools	Engineers, Designers Planners Academia, Engineers, Government Environmental authorities, NGO	6

Source: (Adapted from 1-Amarasinghe, 2018; 2-Asadollahfardi, Asadi, & Karimi, 2015; 2 3- Frankl & Rubik, 2000; 4- Lewis & Demmers, 1996; 5- McManus & Taylor, 2018; 6-Van Langenhove, 2009; 7-Zabalza Bribián, Aranda Usón, & Scarpellini, 2009)

LCA integration to the construction industry in developed countries has been strengthened due to the increasing interest in assessing building environmental performances over its lifecycle and due to the considerable attention in reducing environmental impacts generated by the construction industry (Bilec, Ries, & Matthews, 2009). Dewulf et al. (2009) highlighted that professionals such as engineers, architects, academics, and planners in developed countries actively participate in organising workshops and publishing several handbooks (e.g., International Reference Life Cycle Data System Handbook (ILCD)) on LCA, which could be identified as a positive factor for establishing LCA within the construction industry.

A further indication of the increasing importance of LCA is the development of a novel concept called "Environmental Product Declarations" (EPDs) for environmental communication (Vigovskaya, Aleksandrova, & Bulgakov, 2017). An EPD could 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 and engineers to select eco-friendly materials or products for construction (Fava, 2006). Moreover, there is an increasing interest in developing more and more green buildings in developed countries. The erection of green buildings requires complete LCA to assess harmful environmental impacts during the entire building lifecycle. Hence the increasing interest in developing green buildings provides a strong foundation for the adoption of LCA within the construction industry (Singh et al., 2011).

Governments, environmental authorities, research bodies, and industry professionals become gradually aware of the environmental impacts generated by the construction industry, then environmental assessment becomes increasingly significant in developed countries (Reap, Roman, Duncan, & Bras, 2008; Zhang, Wu, Yang, & Zhu, 2006). Therefore, most of the governments and policymakers across the world promote and encourage environmental assessments to predict possible environmental impacts through the whole value chain (Guinee et al., 2010). Subsequently, LCA has been widely incorporated into environmental policies 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 as a core element in support of actions to build ecologically sustainable buildings in developed countries like USA, Europe, Canada, Australia, Japan, Korea, and forthcoming booming economies such as India and currently China (Guinee et al., 2010; Kögler & Goodchild, 2017).

Furthermore, increasing awareness of environmental impacts generated by constructions, coupled with pressures from numerous stakeholders such as regulatory agencies, government, and environmental authorities have keen on introducing “the green building movement” in connection with the LCA (Singh et al., 2011). As well as, the 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 four IV. For instance, the LEED rating system provides three points for the implementation of “cradle to grave” LCA. The LCA of the two references and recommended building designs need to be compared, and the LCA must consider six impact categories, such as global warming, acidification, eutrophication, ozone depletion, smoke formulation, and non-renewable energy use. For at least three impact categories, the required proposed building should be reduced by at least 10%. BREEAM agreed with the principles stipulated in the LCA standard and has incorporated building LCA into BREEAM since 2011, and two credits were included in BREEAM UK New Construction to the implementation of LCA of buildings. Furthermore, the German Sustainable Building Council (DGNB), Green Building Initiative (GBI), and Green Globes rating system in the USA could be identified as other programs that have been using LCA to analyse building lifecycle while promoting LCA application within the construction industry. The purpose of LCA integration to the certification processes, standards, and green building codes is to encourage professionals in the construction sector to analyse and compare different building materials and structural designs based on its environmental impacts to make informed decisions during the building construction processes (Vigovskaya, Aleksandrova, & Bulgakov, 2017).

When it comes to the perspective of academia and research bodies, LCA is still becoming an active field for research. Therefore, academics are interested in doing research-related activities on LCA concerning the construction industry (Haes, et al., 2004). Apart from that, Asadollahfardi, Asadi, and Karimi (2015) and Finnveden et al. (2009) identified that environmental modeling software packages have recently been introduced as a collaborative activity of academia and the construction industry, which make it easy to implement LCA to the construction sector. Szalay (2007) further elaborated that, academia, government, environmental authorities, and the construction industry are collaboratively involved in developing different LCA databases such as ATHENA for the US and Canada and GaBi and SimaPro for Europe. Additionally, Arena and De Rosa (2003) and Treloar, Love, and Crawford (2004), highlighted that traditional LCA technique requires more data as well as time and resource to perform. Hence, a novel approach has developed by stakeholders in academia, environmental authorities, and the construction industry and named as “streamlined LCA” that require fewer data to perform LCA.

As well as academia, government and environmental authorities together initiate Institute for Environmental Research and Education (IERE) in America to undertake and disseminate fact-based and comprehensive research on the area of LCA (Business network for energy, 2012). Further, environmentalists also play a prominent role in Europe and North America by promoting LCA through the United Nations Environmental Programme (American Wood Council, 2010).

2.3.2 Negative Factors Influencing on LCA Application in the Construction Industry

This section comprises the negative factors faced by different stakeholders in developing countries in an attempt to establish LCA in the construction industry. Several studies highlighted various negative factors faced by different stakeholders for establishing LCA in the construction industry. Summary of the literature findings of the negative factors with relevant stakeholders is presented in Table 2.2.

Table 2.2: Negative Factors Faced by Different Stakeholders in establishing LCA for the Construction Industry

No	Negative Factors	Relevant Stakeholder	Ref. Code
I.	Unavailability of experienced LCA professionals	Engineers, Planners, Designers, Environmental Authorities, Academia	1,3,4,14, 23
II.	Prejudice on LCA for the buildings are more complex than LCA for conventional products	Investors, Planners, Designers	4,6,7,12,20,22
III.	The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)	Investors, Environmental Authorities	5,8,12,14,15,17,18,23, 24
IV.	Unavailability of accurate LCA data with respect to the construction sector	Engineers, Designers, Planners, Government, Regulatory agencies, Policymakers	3,5,7,9,10,11,12,13,14,16,18,19,20,23
V.	Limited awareness about LCA as a decision-making tool to assess building environmental performances	Designers, Planners, The general public,	3,17,18
VI.	Absence of proper legislative initiatives and competent authorities to encourage the application of LCA	Investors, government, Regulatory agencies, Policymakers	21
VII.	Lack of favorable governmental incentives	Government, Policymakers Regulatory agencies	14,19,24
VIII.	Non-integration of LCA with building management software packages	Environmental authorities, Academia,	24
IX.	Problems in understanding LCA results	The General public	19,24
X.	Lack of appreciation for the application of LCA	Environmental authorities, Academia,	19

XI.	Limited availability of platforms to publicise LCA concept	Academia, Environmental authorities	2

Source: (Adapted from 1-Abeysundara, Babel, & Gheewala, 2009; 2-Amarasignhe, 2018; 3-American Institute of Architects, 2010; 4-Anastaselos, Giama, & Papadopoulos, 2009; 5--Arena & Rosa, 2003; 6-Chau et al., 2007; 7- Chau, Leung, & Ng, 2015; 8-Evans & Ross, 1998; 9-Finnveden et al., 2009; 10-Finnveden, 2000; 11-Haes, Jolliet, Norris, & Saur 2002; 12-Hendrickson, Horvath, Joshi, & Lave, 1998; 13-Jönsson, 2000; 14-Lewis & Demmers, 1996; 15-Malmqvist et al., 2011; 16-Ostermeyer, Wallbaum, & Reuter, 2013; 17-Paulsen, 2001; 18-Pour-Ghaz, 2001; 19-Reed, 2012; 20-Saghafi & Hosseini Teshnizi, 2011; 21-Seidel, 2016; 22-Singh et al., 2011; 23-Staller & Tritthart, 2010; 24-Zabalza Bribián et al., 2000).

LCA has been frequently used in many industries such as consumer product design, automotive design, and equipment manufacturing (Keoleian, Phipps, Dritz, & Brachfeld, 2004; Spitzley, Grande, Keoleian, & Kim, 2005) although, the application to the construction industry is a state-of-the-art, since the last ten (10) years (Buyle et al., 2013). Correspondingly, a high proportion of LCA studies have addressed product development processes (e.g., paper production process and cement manufacturing process) rather than focusing on the construction sector in developing countries (Huntzinger & Eatmon, 2009; Kohler, König, Kreissig, & Lützkendorf, 2010). As per the explanation of Basbagill, et al. (2013) compared to products manufactured in industries, civil engineering structures are unique, its lifetime is longer and civil structures are complicated with multiple functions. Hence the adoption of LCA to the construction industry has been weakened. Hence, many stakeholders, such as engineers, architects, planners, and designers, may reluctant to apply LCA due to its complexity.

Moreover, it was pointed out that there is a scarcity of LCA expertise to perform LCA in developing countries, and it is negatively affected by stakeholders such as engineers, architects, planners, and designers (Arena & Rosa, 2003). Jonker and Harmsen, (2012) emphasised that a complete LCA generally requires months to complete even for a qualified and experienced LCA professional, as data collection consumes more time and resources. The unavailability of LCA databases in developing countries has created another practical bottleneck for the implementation of LCA (Saghafi & Hosseini Teshnizi, 2011). Supportively, Scheuer, Keoleian, and Reppe (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 specialised knowledge needed by the complex LCA have been negatively affecting to the establishment of LCA in the construction industry in developing countries (Ardente et al., 2008). Hence, it has emphasised that the application of LCA to the construction industry is more complex and expensive (Ding, 2014), and also it limits stakeholders such as; contractors, consultants, investors, architects, and engineers' interest in applying LCA.

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 in between the construction industry requirements and academic researches (Pour-Ghaz, 2013). Furthermore, Amarasinghe (2018) stated that the lack of a platform to coordinate government authorities, academia, LCA practitioners, environmentalists, scientists, and users, to share knowledge for the continuous improvement of LCA would threaten the spread of LCA within the construction industry in developing countries. Optimising 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 putting this knowledge into practice due to the lack of integration of LCA with modern management software packages such as BIM (Oviir, 2016). Moreover, this could negatively affect the academics, policymakers, regulatory agencies, and environmental authorities in performing LCA. Additionally, lack of legislative governance measures to encourage building developers and designers to apply

LCA in the early design stage barricade the application of LCA into the construction industry. As per the opinion of Udo de Haes (2004) and Ometto, Filho and Souza (2006) highlighted that LCA has succeeded as a method for the environmental assessment in developed countries, while technical assistance and financial support are still required to establish LCA in developing countries.

2.4 Establishing LCA in the Construction Industry: Key Stakeholders

According to section 2.3.1 and 2.3.2, environmental problems generated by the construction industry are posing numerous daunting challenges that affect the quality of the environment (Barth, 2011). These environmental issues seemingly become more complex, unpredictable, and multi-scale and affect a wide variety of stakeholders and demanding novel technical solutions, new collaborations, and societal transformations to mitigate these environmental impacts (Geels, 2005). Consequently, LCA came into practice as a remedy to mitigate possible environmental impacts generated by the construction industry (Finnveden & Moberg, 2005). Nevertheless, LCA integration to the construction industry is stagnating in developing counties (Ometto, Filho, & Souza, 2006; Udo de Haes, 2004). According to the identified positive factors acquired by developed countries, it has been proved that LCA integration to the construction industry needs to be dealt with in collaboration with the diverse stakeholders such as academics, researchers, environmentalists, environmental managers, investors, architects, government bodies, regulatory agencies, the general public, policymakers, designers, contractors, and engineers. It has proved that each of the stakeholders has to contribute individually or collectively to integrate LCA into the construction industry. Accordingly, it needs to be developed bilateral and multilateral relationships between stakeholders for LCA establishment to the construction industry. Furthermore, findings reveal that lack of contribution and coordination amongst above-identified stakeholders poses challenges to establish LCA into the construction industry in developing countries.

According to the emerging nature of innovation management consists of a variety of implications that could not be handled by a single stakeholder due to the lack of competences and resources (Afonso, De Oliveira Monteiro, & Thompson, 2017). It is further confirmed and highlighted that OECD (2009), in the modern innovation era, competes individually with pure technology has become harder and difficult to come up with the appropriate solutions. As exposed by Bogers and West (2012), the interdependence between stakeholders could be identified as a way of emerging innovation, where resources and capabilities are disseminated among a wide network of stakeholders. Hence, stakeholders such as academics, researchers, environmentalists, environmental managers, investors, architects, government bodies, regulatory agencies, the general public, policymakers, designers, contractors, and engineers need to collaborate and compete with each other through mutual interactions to establish LCA enable construction industry.

2.5 Intermingling Key Stakeholders towards LCA Establishment in the Construction Industry: An Innovational Approach

The creation of knowledge could be identified as the process of creating new "innovations" (Carayannis & Campbell, 2006, 2009, 2010). On the other hand, knowledge application and use of knowledge overlap with the concept of "innovation," and the concept of innovation assist in leveraging knowledge application, use, and diffusion as innovation translate knowledge into application. Smelser and Baltes (2001) stressed that the concept of innovation is deliberated as a multidimensional and nonlinear phenomenon, which considerer complex relational ecosystems with concurrent developments of value co-creation through collaboration. When it comes to innovation in the construction industry, it comprises multiple stakeholders in society with diverse motivations (Whyte & Sexton, 2011). As well as in the domain of innovation management theory, the problem is not "why" but rather "how" different challenges could be solved (Baccarne et al., 2016).

Hence, it must perceive LCA integration to the construction industry not as a challenge or problem but rather as a priceless opportunity to think and work innovatively and effectively to find new solutions. Therefore, the problem of LCA integration to the construction industry in developing countries could be dealt with with the use of innovation management. Although a sense of urgency to take immediate action to protect the environment by establishing LCA in the construction industry is widespread, people are still struggling to discover sustainable and speedy ways to establish LCA in the construction industry. Sivunen, Pulkka, Heinonen, Kajander, and Junnila (2013) posited that the innovation processes in the construction industry could be better organised by utilising innovation models. In the search for innovative ways to cope and deal with this tension, several types of innovation models could be identified, such as the Bounded Innovation Management model (BIMM), Adaptive Innovation Management Model, Innovative Activity Models, Model of Innovation Management System (IMS) and Helix Innovation Models (Carayannis et al., 2017; Eito–Brun & Sicilia 2017; Fielden & Malcolm, 2006; Kłos, Skrzypek, & Dąbrowski, 2016; Shankar & Spanjol, 2005). In BIMM where organizational culture, creativity, and culture productivity relation are taken into account (Fielden & Malcolm, 2006). In IMS it suggests an integrated model with an Enterprise Resource Planning (ERP) that includes a product and process configurator (Kłos, Skrzypek, & Dąbrowski, 2016). Innovative Activity Models are presented for small software companies, recognizing the practices and activities of developing innovative products and highlighting the relationship between innovation management activities and software development processes (Eito – Brun & Sicilia 2017).

Amongst the different types of innovations models mentioned above helix innovation models have been evolved with the time and used significantly in different perspectives than other innovation models. Therefore, helix innovation models select as the best model to tackle the existing challenges in establishing LCA in the construction industry.

2.5.1 Evolution of Helix Innovation Models

When considering helix innovation models, basically three types of Helix Models could be identified, such as Triple Helix, Quadruple Helix, and Quintuple Helix, which are topographically similar, with varying degrees of dimension and complexity (Carayannis & Campbell, 2011). The Triple Helix Model aims to produce and using knowledge in the context of "Academia- Government- Industry" cooperation (Etzkowitz & Leydesdorff, 2000). This model places a particular emphasis on 'tri-lateral networks and hybrid organizations where the aforementioned three (03) helices overlap (Carayannis et al., 2017). Furthermore, Triple Helix focuses on top-down academia, government, and industry perspectives (Park, 2013). When it comes to the Quadruple Helix, it broadens the Triple Helix by appending an additional helix called the "society" (Carayannis & Campbell, 2009; Cavallini, Soldi, Friedl, & Volpe, 2016). Whereas Quadruple Helix concentrations on both top-down academia, government, and industry perspective, as well as bottom-up and middle-level society's grassroots initiatives, which are support to make efficient and effective government, industry, and academia practices (Park, 2013). Finally, the concept of Quintuple Helix contextualises the Triple Helix and Quadruple Helix by adding more helix named "environment" (Carayannis & Campbell, 2010; Carayannis and Rakhmatullin 2014). And this ensures the aforementioned all top-down, bottom-up, and middle-level practices are embedded in Quintuple Helix (Park, 2013). Figure 2.3 is showed aforesaid three (03) models.

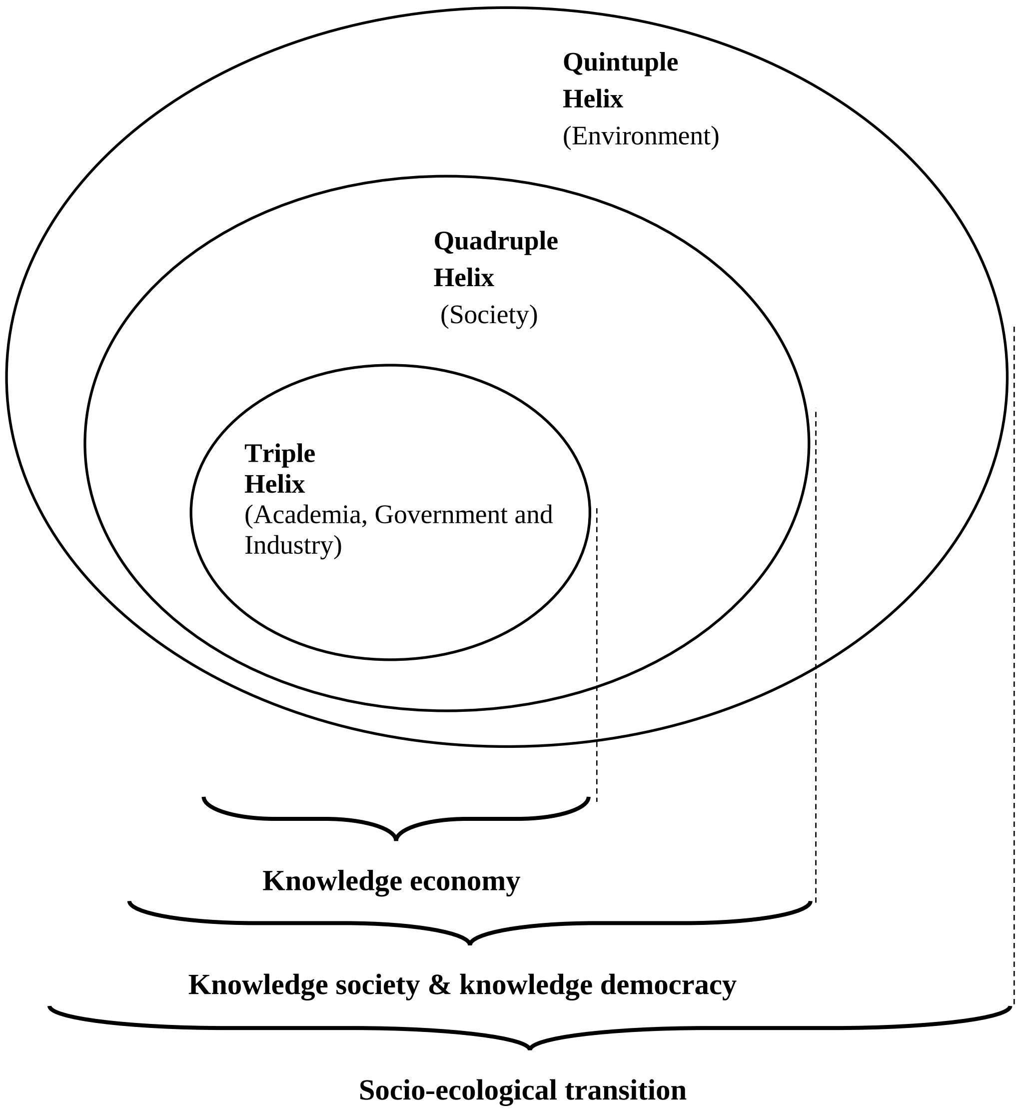

Figure 2.1: Three Types of Helix Models

Source: (Adapted from Carayannis, Barth, & Campbell, 2012)

2.5.2 Quintuple Helix Innovation Model

Quintuple Helix is used to visualise the new knowledge, know-how, and innovations for better sustainable development in a democratic society by dividing the democratic society into five (05) contenders (Carayannis & Campbell, 2010). Quintuple Helix Model characterises five (05) contenders (Carayannis, Barth & Campbell, 2012) namely, (01) academia, that generates and distributes newly acquired knowledge; (02) industry, that manage, possesses, and develops economic capital; (03) the government, that creates legal and political capital; (04) the society, that generates social capital, and (05) the environment, that holds natural capital (Park, 2013). More details about five (05) contenders shown in Table 2.3

Table 2.3: Role of Contenders in the Quintuple Helix Innovation Model

Contenders	Description about contenders	Ref. Code
Academia	• Academia consists of universities, schools, and higher education systems which focus on the "intellectual capital" (e.g., academic entrepreneurs, researchers, and students, etc.) and "human capital" who are resourced persons involved in creating new knowledge and technologies	5, 17
	• Currently, education systems are progressively being regarded as the powerful driving factor for innovation, as universities responsible for making graduates with skills and knowledge. Hence it has become a "seedbed" for innovation	21
	• The education system made a substantial impact on economic development, by providing highly skilled graduates for local firms with their specialised experience	2
	• Moreover, apart from traditional education roles, academia perform activities of research, community development, and dissemination of knowledge into society to foster the innovation	13,14,15
	• As more, investments into the contender of the academia assist in facilitating new research laboratories and new equipment to provide better facilities to conduct research activities, and it would also become a greater outlet for innovations	8
Industry	• The industry comprises with different types of industries and firms and it holds the "economic capital" and "financial capital" (e.g., machines, entrepreneurship, products, technology, and money, etc.) of the state	5, 6, 10,

	• Through the input of knowledge to the economic system, innovations such as new green products, new types of jobs, new green services, together with decisive greener economic growth would be created	11
Government	• This could be identified as the most significant contender on the formation of a knowledge economy as it owns the 'democratic capital' of knowledge (e.g., plans, policies, laws, incentives, partnerships, and ideas, etc.)	5, 6, 10, 11
	• The political system plays an increasingly significant role in facilitating a regulatory environment to encourage innovation	20
	• Policies, laws, and legislation are some tools used to influence society	9
	• Moreover, maintenance of sufficient institutional capacity, active participation, and mobilisation of stakeholders through government policy coordination displays the state possibility of creating a knowledge economy	5
	• Governments are formulated regulatory system as well as provide financial support, tax breaks, incentives, and infrastructure to promote the creation of links between academia and firms	1
	• The government also promote entrepreneurship by adjusting public policies, resolving market failures, and establishing market rules	4
Society	• 'Media-based and culture-based public' and 'civil society': this refers to the values and culture of society, and it owns "social capital" (e.g. solidarity and lifestyle, etc.) and "information capital" (social networks, news, and communication)	5
	• Civil society includes citizens, labor unions, Non-Governmental Organisations (NGOs), consumers, and users	16
	• Moreover media and culture-based public refers to the values and culture in the society such as knowledge of culture, creative industries, media, innovation in the culture, multiculturalism, and creativity, and lifestyles, arts, multi-level innovation methods in universities of the arts and sciences which raise innovations	2, 19
	• These heterogeneous and diverse settings of culture help to foster creativity, which is very much essential and necessary to create and produce new knowledge and innovations	7
Environment	• Natural environments of economy and society frame innovation and knowledge in the context of the natural environment	5,6
	• For instance, the area of environment is insofar important to the creation of knowledge for innovations, as it contributes significantly to the preservation of the natural environment	6, 12
	• The creation of new knowledge in the contender of environment results in less destruction, exploitation, wastefulness, and contamination	5, 6,11

Source: (Adapted from 1-Afonso, De Oliveira Monteiro, & Thompson, 2017; 2-Armstrong & Taylor, 2000; 3- Barth, 2011; 4- Cai & Liu, 2014; 5- Carayannis & Campbell, 2009; 6- Carayannis & Campbell, 2010; 7- Carayannis & Campbell, 2011; 8-Carayannis & Campbell, 2014; 9- Carayannis & Rakhmatullin, 2014;10- Carayannis, 2004; 11- Carayannis, Barth, & Campbell, 2012; 12- Carayannis, Campbell, & Orr, 2015; 13- Carayannis et al., 2017; 14- Etzkowitz, 2002; 15- Gibb, 2005; 16- Grundel & Dahlström, 2016; 17- Kimatu, 2016; 18- Marçal et al., 2017; 19- Naylor & Florida, 2003; 20- Nowotny, Scott, & Gibbons, 2013; 21- Sharma, Kumar, & Lalande, 2012; 22-Tuunainen, 2002)

2.5.3 Modifying Quintuple Helix Model

Figure 2.4 is presented the one of the developed Quintuple Helix Models.

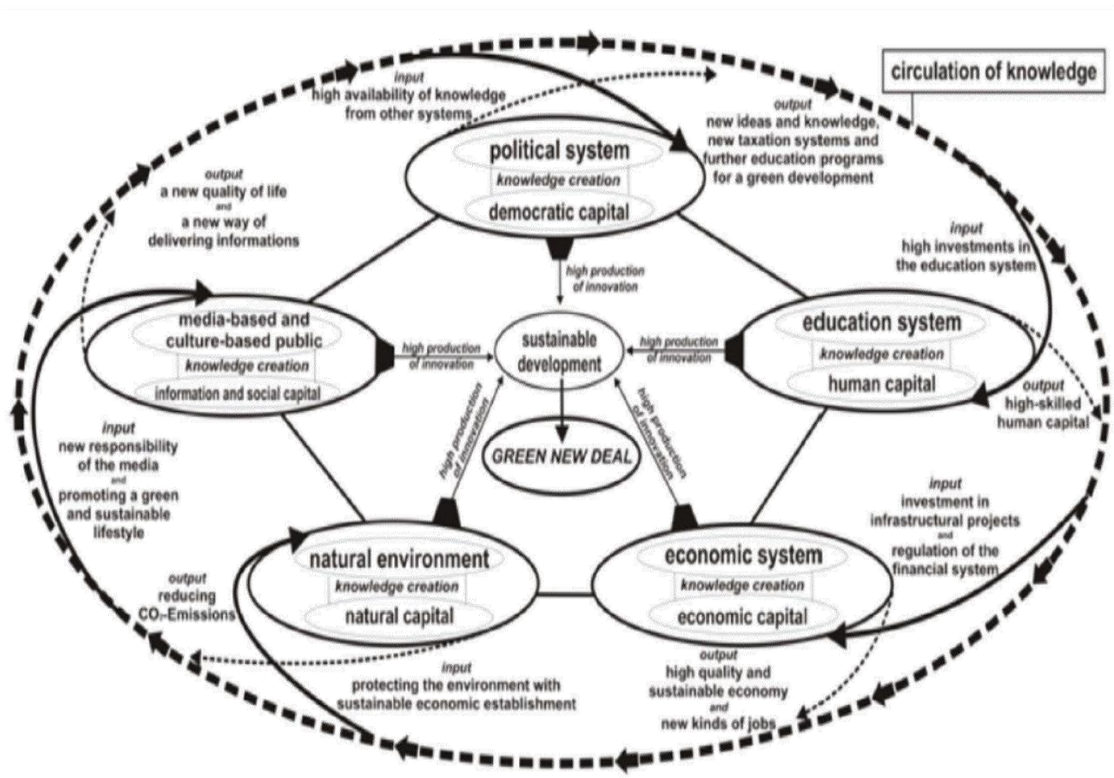

Figure 2.2: Developed Quintuple Helix Model for a Green New Deal

Source: (Barth, 2011)

The Quintuple Helix Innovation Model presented by Barth (2011) is a structure that facilitates knowledge, innovation, and sustainable competitive advantages. According to Carayannis, Barth, and Campbell (2012), the Quintuple Helix innovation model contains five (05) helices and these five (05) helices act like contenders and knowledge transfers from contender to contender in a spherical manner. Each of the contenders has unique resources. If knowledge enters into one (01) contender, it leads to creating new knowledge or innovations (Grundel & Dahlström 2016). Hence, it could be identified that the resource of knowledge is the most vital 'commodity' in the Quintuple Helix Innovation Model, as the flow of knowledge continually stimulates and generate new knowledge and innovations (Barth, 2011). Overall, the newly created knowledge of one (01) contender (e.g., ideas, goals, and investments, etc.) acts as an input to the next contender. It could be identified that "knowledge creation" is the outcome of the input, which is formed through an exchange of new inventions, basic knowledge, or results of research. On the other hand, the output of knowledge creation is the production of innovations and newly created know-how. Subsequently, the output of know-how is new input for another contender of the society (Carayannis & Campbell, 2010). Likewise, all contenders in the Model of Quintuple Helix influence one another through knowledge to promote sustainability through the novel, advanced and pioneering innovation; moreover, it could be noted that all contenders in a Quintuple Helix are interacting through knowledge circulation (Carayannis, Barth, & Campbell, 2012). Moreover, this model explains and emphasises the importance of integration between five (05) contenders to form the architecture of innovation in a wider perspective (Park, 2013). Hence, the model of Quintuple Helix is suitable to understand and investigate how knowledge is created and exchanged between different contenders (Baccarne et al., 2016).

2.6 Aligning essential contextual stakeholders for establishing LCA in the construction industry with the Quintuple Helix Innovation Model significant contenders

Implementation of LCA to the construction industry could be seen as a collaborative activity that would have an impact on several stakeholders. Moreover, it could be highlighted that LCA integration to the construction industry is a collective activity and innovation foster by the stakeholders mentioned above. According to the prevailing literature, it could be identified that suitable framework for the analysis of such complex as well as collaborative innovation is the "Quintuple Helix Innovation Model" as it creates synergies between academia, government, construction industry, society, and environmentalists (Baccarne et al., 2016). According to the findings derived from the section 2.3, it has been proved that LCA integration to the construction industry needs to be dealt with in collaboration with the diverse stakeholders of academics, researchers, environmentalists, environmental managers, investors, architects, government bodies, regulatory agencies, the general public, policymakers, designers, contractors, and engineers. Accordingly, these stakeholders could be categorised into five (05) contenders in the Quintuple Helix Innovation Model such as (I) academia (including academics and researchers), (II) government (including regulatory agencies, policymakers), (III) construction industry (including investors, architects, designers, contractors, and engineers), (IV) society (including non-governmental organisations and non-profit organisations) and (V) environmentalists (including environmental managers, sustainability consultants, environmental engineers).

Hence, it is proposed that the Quintuple Helix innovation model is a better framework to analyse the LCA establishment to the construction industry through the joint of knowledge production than other aforesaid traditional approaches (Yoon, Yang, & Park, 2017). Especially, other traditional approaches such as Triple Helix and Quadruple Helix do not focus on environmental aspects. Sunina and Rivza (2016) found that this model further helps to investigate the existing situation and demonstrate future trends to improve the cooperation between quintuple parties. Hence, based on the prevailing literature, the Quintuple Helix Model could be identified as the most suitable model used to visualise and analyse the impacts and scientific interconnections between five (05) contenders in the process of LCA establishment to the construction industry.

2.7 Conceptual Quintuple Helix Innovation Model for LCA Integration to the Construction Industry

Figure 2.3 presented the conceptual Quintuple Helix Innovation Model for the establishment of LCA in the construction industry. The conceptual Quintuple Helix Innovation Model contains five contenders (e.g., academia, government, construction industry, society, and environmentalist) with their strengths/opportunities and weaknesses /threats for establishing LCA in the Sri Lankan construction industry. Strategies were placed in the middle of the conceptual Quintuple Helix Innovation Model. Strategies were used to address the weaknesses/threats in establishing LCA for the Sri Lankan construction industry. Knowledge transfers from contenders to contenders in a spherical manner. Each of the contenders contributes to the knowledge circulation process through the outputs. Further, each of the contenders taken inputs from the knowledge circulation process to crate LCA enabled construction industry in Sri Lanka.

2.8 Summary

There is a crucial requirement to establish LCA for the Sri Lankan construction industry as a solution to reduce the increasing environmental impacts. Developing countries should strive to integrate the strengths and opportunities which are enjoyed by developed countries in establishing LCA for developing the country's construction industries to facilitate a resourceful background to support the LCA application. Developing countries should strive to minimise the weaknesses and threats in establishing LCA in their construction industries. LCA integration to the construction industry needs to be addressed as a collaborative activity between five (05) contenders; academia, government, construction industry, society, and environmentalists. Hence, the Quintuple Helix Innovation Model identified as the most suitable model for the analysis of such collaborative innovation introduced by LCA into the construction industry because the model has a synergy among academia, government, construction industry, society, and environmentalists.

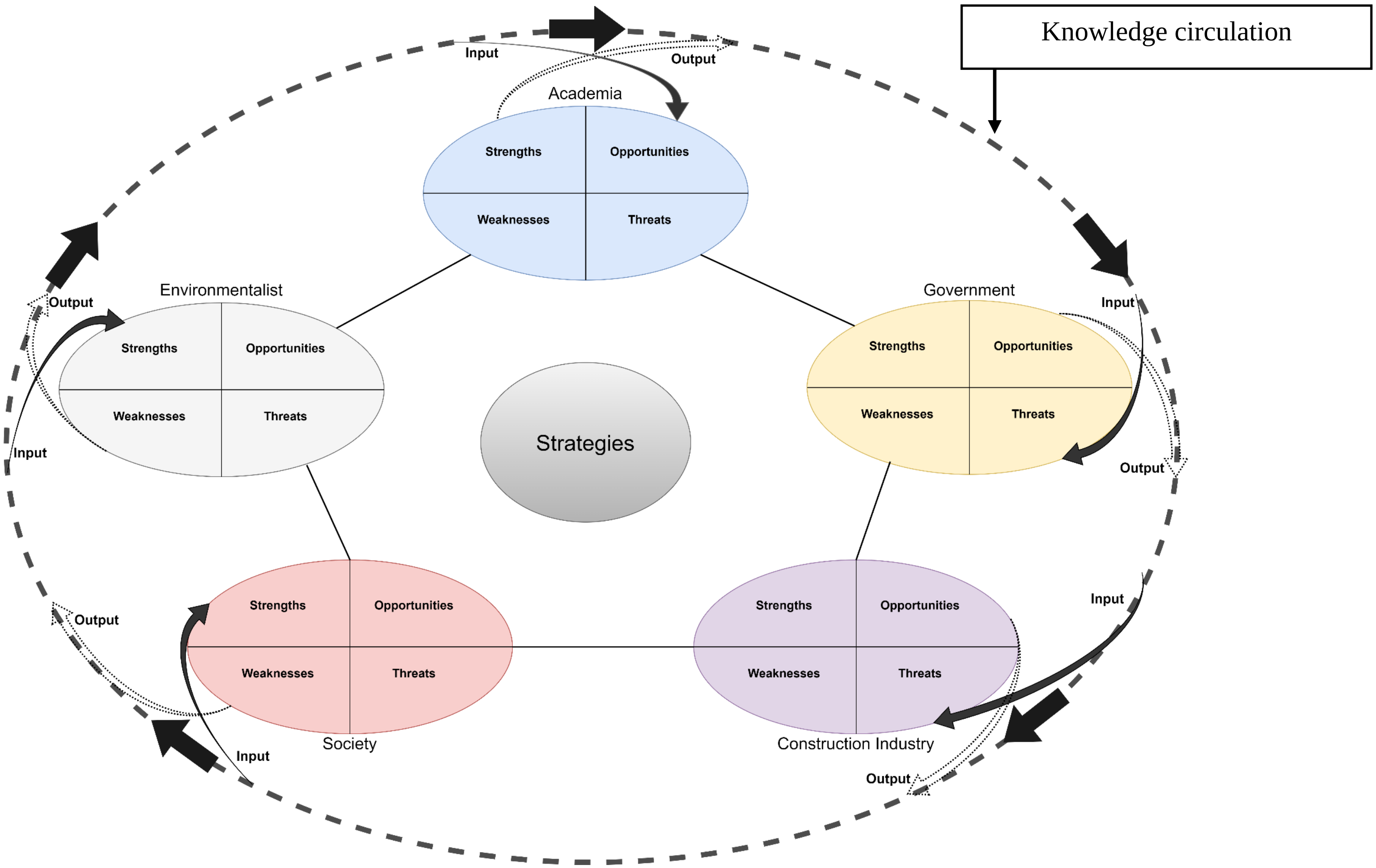

Figure 2.3: Conceptual Quintuple Helix Innovation Model for Establishing LCA in Construction Industry

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.0 Introduction

Chapter two provides a broad understanding of the researched knowledge domain through the literature review. This chapter points out ways to accomplish the aim and objectives of the study, as 'research methodology' is the art of conducting research, which aims to provide a work plan for research. Further, this chapter elaborated on the research design, research approach, and research method and research technique used for data collection and data analysis.

3.1 Research Design

Maxwell (2005) emphasises that research design illustrates the combination of research methods that collect and analyse data to achieve the aim of the research. Moreover, the research design illustrates the arrangement of tasks, which are used to collect and analyse the information to provide satisfactory results for the research questions (Creswell, 2014). Therefore, the research design is based on the nature of the research question (Maxwell, 2013). The research design of this study is discussed throughout this chapter by providing justifications for selecting the research approach, research methods, and techniques used for data collection, and analysis.

3.2 Research Approach

Research approaches can be identified in the two (02) extreme ends, i.e., qualitative approach and a quantitative approach, which differ from one another in terms of their strengths and weaknesses (Novikov & Novikov, 2013). The mixed research approach is a combination of qualitative and quantitative methods to make up for the deficiencies of other methods (Johnson, Onwuegbuzie, & Turner, 2007). The decision to choose the appropriate research approach depends on the nature of the research question (Kothari, 2004). Table 3.1 is presented with a comparison of quantitative and qualitative methods with the requirements of this study.

Table 3.1: A Comparison of the Quantitative Approach and the Qualitative Approach with the Requirements of this Study

Quantitative Approach	Qualitative Approach	Requirements for the study
• This approach is statistics-based and focuses on numerical data. Further, this aims to conduct objective analysis involved with numerical data that could be computed using several statistical methods (Guetterman, 2020)	• This approach is descriptive-based and focuses on qualitative data. Further, this aims to conduct subjective analysis involved non-statistical data that cannot be calculated (Catterall, 2000)	• This research focuses on investigating the Quintuple Helix Innovation Model-based significant contenders' contributions to establish LCA in the construction industry, which generates a high volume of **qualitative data**
• The sample size is large, and data are randomly selected from the population, and the results of the study could be generalised to the whole population. Hence, this could be constrained by insufficient data available to generate a high rate of respondents. Therefore, it is more appropriate for researches, which could draw a large sample of respondents (Burton, Carrol, & Wall**,** 2002)	• The sample size is small as well as non-representative from the entire population, so it is recommended to use a qualitative approach to explore emerging concepts through in-depth investigations. More appropriate for researches, which could draw a small sample of respondents (Leavy, 2017)	• It found out that **only a very few professionals with both practical exposure and knowledge** related to the LCA are available in Sri Lanka, representing the five contenders of the Quintuple Helix Innovation Model. As the application of LCA for construction outputs is at an elementary level in Sri Lanka
• Data collection methods are highly structured (e.g., structured interviews and observations, surveys and document review, etc.) (Nardi, 2006)	• Data collection methods are semi-structured or unstructured (e.g., document reviews, focus groups, in-depth interviews, observations, etc.) (Tracy, 2019)	• **Semi-structured expert interviews** are suitable to obtain comprehensive opinions from the limited number of LCA professionals representing the five contenders of the Quintuple Helix Innovation Model.
• The analysed results of the study are utilised to understand how much or how many times a particular phenomenon occurs using several statistical methods (Taylor, 2005).	• The analysed results of the study are utilised to understand why and how a particular phenomenon occurs (Tracy, 2019).	• This study aims to investigate **why** Sri Lanka does not adopt LCA, and **how** to establish the LCA to the Sri Lanka construction industry with the use of five (05) significant contender roles

This research aims to investigate the Quintuple Helix Innovation Model-based significant contenders' contributions to LCA establishment in the construction industry. According to Table 3.1, the qualitative approach of exploring the experience and views of LCA professionals could be considered as the most suitable approach to study the modern phenomenon of the LCA concept. The lack of application of LCA in Sri Lanka made a constraint to obtain large samples of respondents for the study. Accordingly, it is proposed to adopt the qualitative research approach to carry out a comprehensive investigation to accomplish the aim of this research.

3.3 Research Strategy

The research method can be identified as a strategy, process, or technique used to collect data or evidence for analysis to discover new information to understand the research problem better. There are different types of research methods that could be identified under the qualitative research approach. Table 3.2 discussed the different types of research methods.

Table 3.2: Types of Research Strategies

Type of Research Methods	Description	Reference
Expert interview survey	• Applicable when the research questions are directly pertinent to the particular respondent segments • Could reveal unique perspectives on the problem domain • Effective in gathering individual experience of the problem area • More detailed answers could be obtained from interviewees	(Rook, 2010) and Minichiello Minichiello, Aroni, & Hays, 2008)
Focus group discussions	• Applicable when research questions attempt to explore disparate views through discussion or debate • Disagreements on the problem could be revealed • Effective for gathering shared experience of the problem area	(Rook, 2010) and (Sekaran & Bougie, 2016)
Document analysis	• Collect data based on existing sources, such as government reports, newspaper articles, personal documents or books, etc.	(Creswell, 2014)
Observations	• Effective to gather sensitive information	(Maxwell, 2005)

	• Could get first-hand data through direct observation	
Case study	• Provides an in-depth, and detailed examination of a particular case	(Guetterman, 2020),

A deep understanding of the significant contender roles for establishing LCA in the construction industry is required to achieve the aim of this research. According to Table 3.2, an expert survey is suitable for capturing such an in-depth understanding of the problem domain with the advantage of examining the experiences and knowledge of the experts. 'Experts' refer to people who have extensive and in-depth capabilities in terms of knowledge, skills, and experience through practice and education in specific fields (Nonaka, 2006). Consequently, an expert survey was selected, as the appropriate research method to obtain comprehensive opinions from the limited number of LCA professionals representing five (05) contenders in the Quintuple Helix Innovation Model, after evaluating several optional research methods.

3.4 Research Techniques

Research techniques include data collection techniques and data analysis techniques used to achieve the aim of the study (Corbin & Strauss, 2014). The following research techniques were used in this study.

3.4.1 Data Collection Technique

After recognising the research gaps thorough background study and identifying mainstream literature through literature reviews, the next step is to collect relevant data. The following section discusses the selected data collection technique for the study.

Selected Data Collection Technique for the Study - Repertory Grid Interview Technique

"Repertory Grid Interview (RGI) Technique" was initially developed in 1955 by George Kelly based on his theory of Personal Constructs (Goffin, Lemke, & Koners, 2010). Since then, this technique has been widely used within various contexts as a means of conducting an interview and gathering information in a highly structured manner (Harlim, 2017). The major advantage of using this interview technique is, it allows interviewees to express their personal experiences and ideas about the interview topic using their language and terms (Tan & Hunter, 2010). Hence, it prevents bias with the interviewer and more transparency for the interviewee by helping the interviewee to express his/her views in a more personalised manner. (Edwards, McDonald, & Michelle Young 2009). Once the data has been collected, it is recorded in the form of a grid for analytical purposes. This specific type of structured grid helps with the ability to analyse the data qualitatively. Since it contains the rating scales, the statistical analysis could also be performed on the collected data, simultaneously (Björklund, 2008; Harlim, 2017). Hence, this technique acts as a hybrid method to analyse the information collected from the interviewees by combining both qualitative and quantitative methodologies (Goffin, Micheli, Koners, & Szwejczewski, 2012). Following the above observations, RGIs have been conducted to evaluate the positive factors and negative factors for establishing LCA in the construction industry from an internal vs. external perspective. The "Repertory Grid" comprises of four (04) main components:

1. **The topic**: The topic could be determined as the content of the interview (Björklund, 2008; Goffin et al., 2012). In line with this research, "positive factors and negative factors for establishing LCA in the construction industry" could be recognised as the topic.
2. **Elements**: Elements are the examples that illustrate the topic, and it could be anything like objects, events, experiences, set of actions, behavioral patterns based on the context of the topic (Bourne & Jankowicz, 2017). Defining elements is the first design decision to be taken when recording data and should be aligned with the objectives of the investigation (Edwards et al., 2009). Consistent with this study, several types of positive factors and negative factors could be identified as the elements.
3. **Constructs**: Constructs are considered as the most important component of the repertory grid because this is the phase where each element is compared with another (Siau, Tan, & Sheng, 2010). This comparison finally produces a set of

statements to illustrate the view of the interviewee about the topic. As stated above, these constructs are presented as opposite poles of a magnet (Goffin, Lemke, & Koners, 2010). Consistent with the RGI technique, interviewees from each contender (e.g., academia, government, construction industry, society, and environmentalists) were asked to evaluate and give their opinion on the identified elements (e.g., positive factors and negative factors) for establishing LCA in the Sri Lankan construction industry from an internal perspective vs. external perspective based on their knowledge and experience. Accordingly, an "internal perspective" and an "external perspective" could be identified as the constructs of this study.

Use of SWOT Analysis: Basis for the Constructs

Accordingly, researchers in the field of strategic management, utilise SWOT analysis which is an acronym of (Strengths, Weaknesses, Opportunities, and Threats) as a foundation for the realisation of internal as well as external factors affecting to the specific project or activity (Böhm, 2009; Helms & Nixon, 2010; Zueva, 2019). Figure 2.2 illustrates the concept of SWOT.

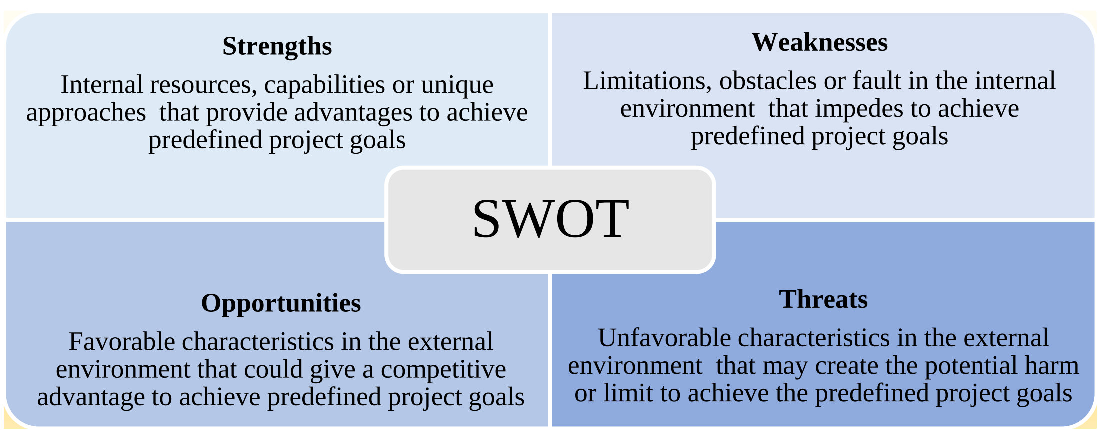

Figure 3.1: Concept of SWOT Analysis

Source: (Adapted from Rizzo & Kim, 2005; Nikolaou & Evangelinos, 2010)

The SWOT analysis is used as a strategic planning technique used to identify internal factors (e.g., strengths and weaknesses) and external factors (e.g., opportunities and threats) that are favorable and unfavorable for achieving specific objectives of a particular project (Ghazinoory, Abdi, & Azadegan-Mehr, 2011; Nikolaou & Evangelinos, 2010; Panagiotou, 2003; Rizzo & Kim, 2005). Li and Gao (2013) and Lozano and Vallés (2007) confirmed that this tool is an incredibly simple yet powerful analysis tool that helps to determine and define internal and external factors to support decision making.

According to the literature, different types of tools and frameworks are used to critically analyse the factors that have an impact on a specific project or an activity. For instance, PEST (Political, Economic, Social, and Technological) Analysis, PESTEL (Political, Economic, Social, Technological, Environmental and Legal) Analysis and SWOT (Strengths, Weaknesses, Opportunities, and Threats) Analysis could be identified as the tools which are used since years to critically analyse the factors that impact on a specific project or an activity (Bîrsan, Shuleski, & Cristea, 2016; Ho, 2014; Sammut-Bonnici, & Galea, 2015). PEST Analysis and PESTEL Analysis are used to discover and evaluate the macro-environmental (external environment) factors that could impact now and in the future for the aspecific project (Peng & Nunes, 2007; Shilei & Yong, 2009). SWOT Analysis is used to analyse both internal and external environments, which could be identified as the most suitable method to categorize identified positive factors and negative factors into internal and external factors.

4. **Ratings:** Once the elements and constructs are defined, they are entered in a specific form on the grid as matched with the context of the topic/research area (Siau et al., 2010). Both "elements" and "constructs" should appear in the grid in an appropriate way as having the ability to rate each element against each construct according to a pre-defined rating scale (Tan & Hunter, 2010). Accordingly, interviewees were requested to evaluate each positive factors and negative factors by selecting any one of the five categories (I – V).

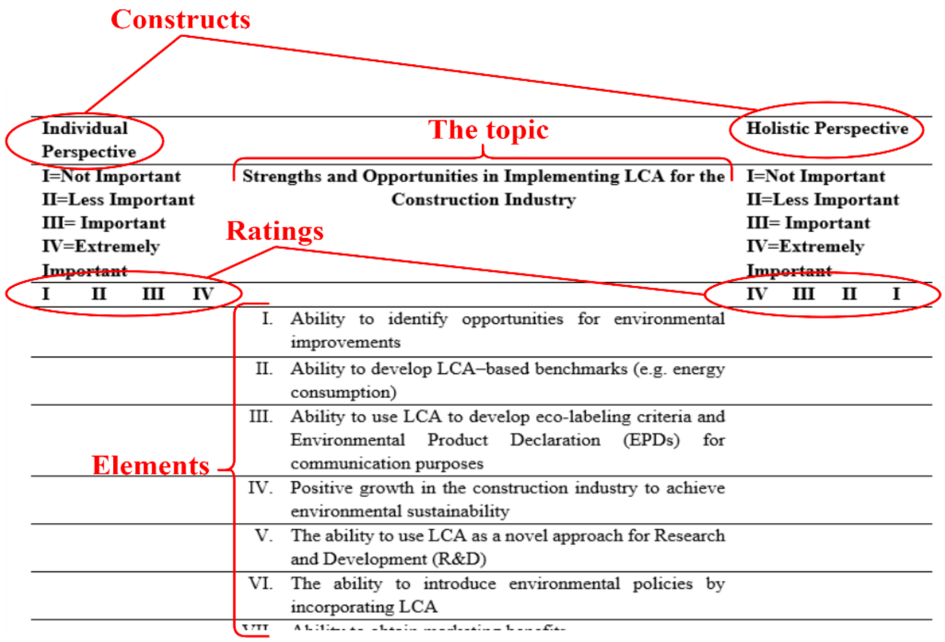

Figure 3.2: Components in the Repertory Grid Interview Technique

3.4.2 Sampling Technique

For all research problems where data could not be collected from the entire population, a sample needs to be selected. A sample could be selected using various sampling methods. According to Creswell (2014), sampling methods could be classified into two categories depending on the nature of the selection of sampling units for the study. Two (02) types of sampling methods could be defined as below,

- Non- Probability Sampling (Non-random sampling techniques)

In the non- probability sampling technique, sampling units of the target population do not have an equal opportunity of being selected for the sample (Trochim, 2005). Hence, the sample would not be fully represented by the target population. Thus, this sampling method is ideally suited for qualitative research, case studies, pilot studies, and for hypothesis development, since the researcher could consciously choose the sampling units for the study (Marshall, 1996). The main techniques (e.g., quota sampling, purposive sampling, snowball sampling, self-selection sampling, and convenience sampling) could be utilised to select a non- probability sample for the study.

- Probability Sampling (Random sampling techniques)

In the probability sampling technique, sampling units of the target population have an equal opportunity of being selected for the sample (Etikan, 2017). Therefore, the sample fully represents the target population, since, in this method, the sample selection process is completely randomised without any bias (Black, 2009). Therefore, the probability sampling method is often associated with experimental studies and research and survey studies. The main methods (e.g., simple random sampling, systematic sampling, stratified random sampling, cluster sampling, and multi-stage sampling) are represented under the probability sampling method.

Selected Sampling Technique for the Study - Judgmental Sampling/ Convenience Sampling

Judgmental sampling could be determined as one (01) of the non-probability sampling techniques (Curtis, 2011). In this technique, researchers could choose the unit (interviewee) for the sample based on their knowledge and professional judgment (Emmel, 2013). The purpose of judgmental sampling is to deliberately select the most suitable interviewees to enable researchers to solve research problems (Gupta et al., 2018). Researchers could use it when they need to obtain the opinions of people who have a high degree of knowledge and experience about the problem domain. Judgmental sampling is usually an extension of a convenience sampling method (Punch, 2005). For example, even if the population includes all cities, the researcher may decide to draw the entire sample from a "representative" city. Considering the purpose of this research, RGI must be conducted by covering five (05) contenders, including (01) academia, (02) government, (03) construction industry, (04) society, and (05) environmentalists. Because of the interviewees were distributed throughout different provinces, the "Western Province" was selected as the representative province for the study by applying a judgmental sampling technique. Moreover, judgmental sampling is most effective only when a few people in the population reflect the quality of the target population that researchers expect. Accordingly, judgmental sampling is identified as the best sampling technique for this study, as LCA professionals from contenders covering academia, government, the construction industry, society, and environmentalists are very difficult to find.

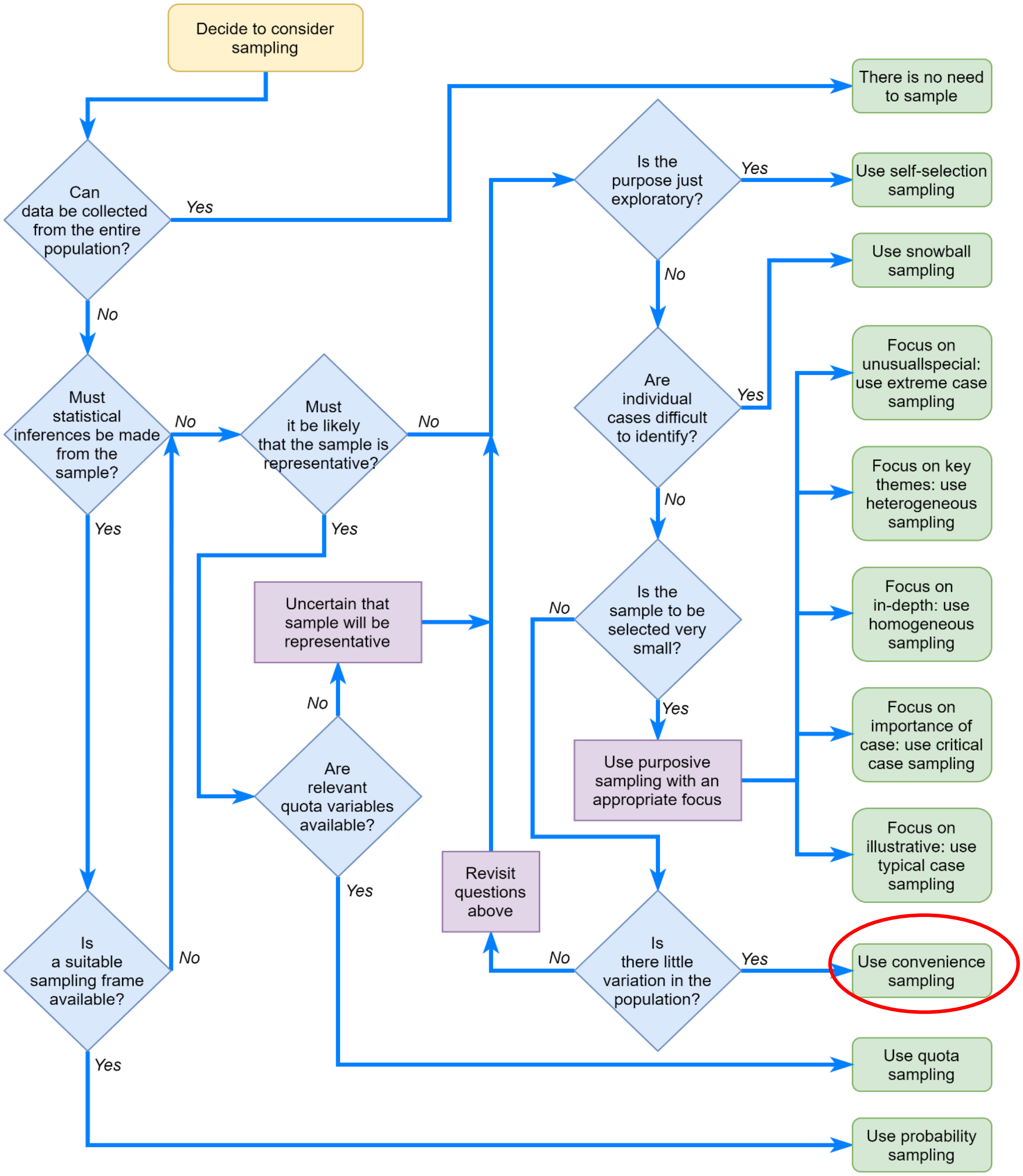

Figure 3.3: Selection Process of the Sampling Method

Source: (Saunders, Lewis, & Thornhill, 2009)

Profile of Interviewees

As the research required an in-depth investigation, RGIs were utilised as the appropriate data collection technique to capture such an in-depth understanding of the problem domain by examining the experiences and knowledge of the interviewees. The interviewees were selected to conduct collateral interviews by targeting five (05) contenders such as (01) academia, (02) government organizations, (03) construction companies, (04) society (NGOs and non-profit organizations), and (05) environmentalists. RGIs were conducted with experts in the area of LCA and environmental sustainability in the construction industry representing all the contenders mentioned above. All interviewees for the study were selected based on their experience and the positions they held in their respective organisations. The judgmental sampling method was used to select interviewees for the research. Table 3.3 presents brief descriptions of the interviewees.

Table 3.3: Profile of Interviewees

Contender	Interviewees	Designation	LCA Experience
Academia	A1	Senior Lecturer – Environmental Sustainability	13 years
	A2	Senior Lecturer- Eco-Innovation	7 years
	A3	Senior Lecturer - Green Technologies	8 years
	A4	Senior Lecturer - Environmental Engineering	10 years
Government	G1	Researcher - Energy and Environmental Economics	10 years
	G2	GHG Mitigation Expert	9 years
	G3	Assistant Director – Sustainability	13 years
	G4	Manager- Sustainable Urban Planning	8 years
Construction Industry	C1	Chief Executive Officer	15 years
	C2	Chief Engineer	17 years
	C3	Chief Engineer	7 years
	C4	Environmental Safety Manager	10 years
Society	S1	Freelance consultant – Sustainable Consumption and Production	7 years
	S2	Sustainability consultant	7 years
	S3	Resource Efficiency and Cleaner Production Consultant	5 years
	S4	Freelance consultant-Innovation Teaching and Implementation	4 years

Environmentalists	E1	Manager- Sustainability Assurance	10 years
	E2	Sustainability Consultant	3 years
	E3	Environmental Engineer	7 years
	E4	Senior Lecturer - Environment Conservation and Management	10 years

3.4.3 Data Analysis Technique

According to section 3.4.1, the data collection technique used for this study is RGI, which yields qualitative data for analysis. Several qualitative data analysis techniques could be recognised, such as content analysis, thematic analysis, interpretative phenomenological analysis, etc. (Glesne, 2016). Besides, data analysis techniques also provide a way to clarify and verify complex data to draw research conclusions. Content analysis is considered to be a suitable and commonly used method for analysing texture data (Thorne, 2000). Therefore, content analysis was used in this study.

The following steps are followed while doing the content analysis

- **Define the units or themes of analysis**

Based on the research question classify content into, three types of themes such as positive factors, negative factors, and strategies. Positive factors are further categorized into two sub-categories such as strengths and opportunities and negative factors are also further categorized into two sub-categories such as weaknesses and threats under five contenders.

- **Develop a set of rules for coding**

Coding involves organizing units into predefined themes. Hence, it is significant to clearly outline the rules of what will and what will not be incorporated to confirm that all units are coded sequentially.

‘S’ is used to symbolize ‘strengths’, ‘O’ is used to symbolize ‘opportunities’, ‘W’ is used to symbolize ‘weakness’, and ‘T’ is used to symbolize ‘threats’. And the following codes are used for the strategies. ‘SA’ is used to symbolize strategies recommended by Academia, ‘SG’ is used to symbolize strategies recommended by Government, ‘SC’ is used to symbolize strategies recommended by the Construction industry, ‘SS’ is used to symbolize strategies recommended Society, ‘SE’ is used to symbolize strategies recommended by Environmentalists, and ‘SC’ is used to symbolize strategies recommended by all contenders.

- **Analyze the results and draw conclusions**

After completing the coding, the collected data is analyzed and draw conclusions in response to the research question.

3. 5 Decision criteria for categorising strengths/opportunities and weaknesses/threats

Findings derived from the repertory grid interview were used to develop respective repertory grids for five contenders. Two (02) repertory grids were developed for each contender, one for strengths and opportunities and other for weaknesses and threats. Elements classified under the construct of an ‘internal perspective’ and were identified as ‘important’ or ‘extremely important’ or both by three or more interviewees (more than 50% interviewees) identified as strengths. Elements classified under the construct of ‘external perspective’ and were identified as ‘important’ or ‘extremely important’ or both by three or more interviewees (more than 50% of interviewees) identified as opportunities. Elements classified under the construct of ‘internal perspective’ and identified as ‘influential’ or ‘extremely influential’ or both by three or more interviewees (more than 50% interviewees) identified as weaknesses. Elements classified under the construct of ‘external perspective’ and identified as ‘influential’ or ‘extremely influential’ or both by three or more interviewees (more than 50% interviewees) identified as threats. Further, elements which do not fulfill the above-mentioned requirements are identified as rejected strengths/opportunities or weaknesses/threats. Figure 3.3 is presented the further details about decision criteria for categorising strengths and opportunities. Figure 3.4 is presented the further details about decision criteria for categorising weaknesses and threats.

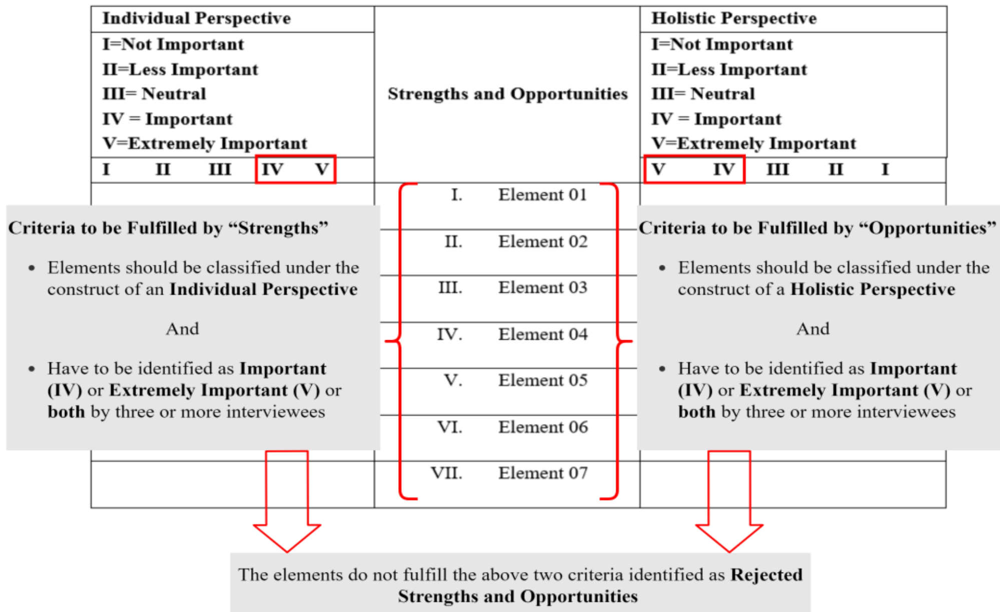

Figure 3.4: Decision Criteria for Categorising Strengths and Opportunities

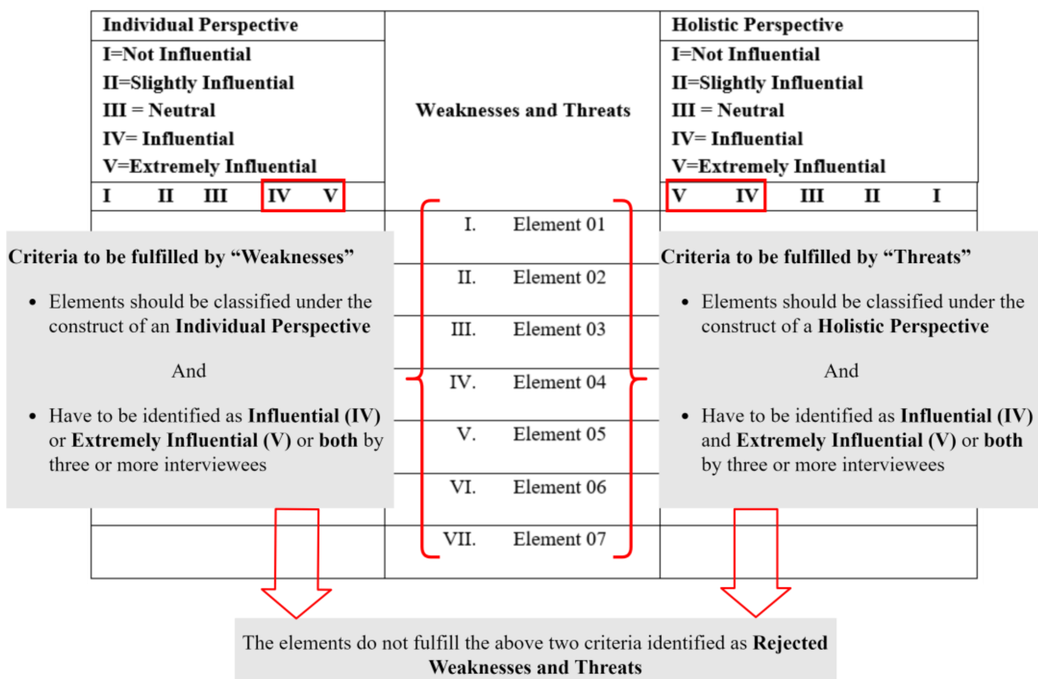

Figure 3.5: Decision Criteria for Categorising Weaknesses and Threats

3.6 Chapter Summary

This chapter describes in detail the research methodology utilised in this study with proper justification. Further, research design, research approach, and research method are described throughout this chapter. A qualitative research approach and an expert interview survey were used in this research. The RGIs were used for data collection, while content analysis is used as a data analysis technique.

CHAPTER FOUR

4.0 DATA ANALYSIS AND DISCUSSION

4.1 Introduction

Chapter three introduce the research method and data collection process of this study. Chapter four presents the comprehensive analysis and discussion of the research findings to achieve the objectives and to draw conclusions. First, the positive and negative factors faced by the five (05) contenders in the innovation model were evaluated in internal perspectives versus external perspectives. Then, results were obtained to develop a SWOT analysis for five (05) contenders. Then, the strategies were proposed to overcome weaknesses and threats faced five (05) contenders for establishing LCA in the Sri Lankan construction industry. Finally, the modified Quintuple Helix Innovation Model was developed by abstracting individual SWOTs to demonstrate the modified roles of contenders in establishing LCA for the Sri Lankan construction industry.

4.2 Analysis and Discussion of the Research Findings

The data collected from interviews were analysed with the use of content analysis to achieve the objectives of the research. The research findings are presented in the following sections.

4.3 Environmental Impacts Generated by the Construction Industry

According to A2, G1, and C3, the construction sector directly contributes to producing a wide range of construction outputs, from private houses to large-scale infrastructural developments such as; expressways, high-end residential and commercial spaces, power plants, hotel and resort construction, and so forth. G3 pointed out that during the last ten (10) years, Sri Lanka has seen a rising trend in the construction sector as a result of the post-conflict situation in the country.

E4 stated that "*the completion of the thirty years (30) long-armed ethnic war in 2009 has rejuvenated the economic activities and caused a boom in the construction sector in Sri Lanka. Consequently, Sri Lanka is heading for a revolutionary change with a significant proportion of reconstruction activities having been started in the East and North*

Provinces of the country. Additionally, the other provinces of Sri Lanka are also perceived to project substantial development activities. The Sri Lankan construction industry has turn into one (01) of the main beneficiaries of the country's speedy economic development, with a contribution of approximately around 7% to the Gross Domestic Product (GDP)."

According to the views of the A2, and S3 construction is not an environmentally compatible process by nature. Construction works have progressively created numerous adverse direct and indirect effects such as pollution (air, noise, and water), GHG emissions, depletion of natural resources, and waste generation. E1 stated that *'the usage of concrete for construction projects has become a crucial environmental challenge as concrete being one of the key building materials utilised in construction projects. Further, Portland cement could be identified as an excellent building material that utilises in concrete due to its excellent binding properties in providing sufficient strength for structural elements. The production process of Portland cement is a significant contributor to Carbon Dioxide (CO_2) emissions to the atmosphere"*.

C1 and C3 emphasised that building constructions and operations both directly and indirectly account for the energy-related CO_2 emissions. C4 mentioned that fossil-fuel-derived energy used in material processing and transportation emit a large quantity of GHG and consumes a considerable amount of energy. E1 and S3 stated that onsite construction activities, operation of construction equipment consumes plenty of fuel and electricity and is also responsible for a significant share of GHG emissions.

Besides, G3 identified that *"infrastructure development projects, demolition works, and renovations are responsible for the generation of an enormous quantity of Construction and Demolition (C&D) waste ending up at landfills due to its non-combustible nature. C&D waste causes negative externalities such as increasing the burden on landfill locations, which are becoming gradually scarce and the contamination from landfills which leads to serious environmental hazards (e.g., water, air, and soil contamination due to the production of methane and CO_2 from anaerobic degradation of waste) and health effects".* Moreover, A1 stated that *"the construction sector is a* *conspicuous user of natural resources, which increases and creates unbearable pressure on the environment by deteriorating the ecological system. Due to the unsustainable extraction of materials and the utilisation of a high volume of natural resources for construction activities. Several natural resources (i.e., land, raw materials, and water) are being used at an alarming rate during the construction process due to the resource-intensive nature of the construction industry.*"

A3 expressed that most of the construction projects are located near the density polluted areas. People who live close to construction projects face health challenges as they are exposed to risks that could affect their health resulting from noise pollution, dust, and vibrations of construction work like earthworks, pile driving, backfill, finishing works, and excavation. For example, E2 stated that the *"Port City Project, which is the largest foreign-funded project in Sri Lanka, creates numerous environmental impacts. This project has destroyed the West Coast beaches from Mount Lavinia to Negombo as a result of coastal erosion during the dredging in this area. Moreover, this caused damages to the coral habitats and fish resources in these areas and the construction process, destroying aquatic life and nearby reefs by generating sediments and other pollutants"*.

From the discussion, it becomes clear that the Sri Lankan construction sector is very important for the country due to an indispensable contribution to the country's economic development. Nevertheless, it is also considered as one (01) of the major contributors to environmental pollution. Also, construction-related environmental impacts have been increasing due to a large number of ongoing construction projects.

4.4 Importance of Managing Environmental Impact in the Sri Lankan Construction Industry

Based on the opinion of interviewees, it was identified that construction works have been generating substantial impacts on the environment across a broad spectrum of onsite, off-site, and operational activities. Further, the rapidly-growing threat of adverse environmental impact of construction projects requires revolutionary mitigating actions in all ramifications. Nevertheless, A5 mentioned that *"most of the decision-makers in the* *construction industry have given priority on economic cost aspects instead of giving priority on managing environmental impacts."* G3 stated that in recent times, the mission of sustainable development had promoted the pressure of demanding the implications towards environmental management practices to improve the environmental performance of the Sri Lankan construction industry. Consequently, the Sri Lankan construction industry has gradually understood the importance of managing environmental impacts while maximising profit.

G2, G4, A1, A4, and C3 noted that the range of typologies is adopted in modern construction practices to minimise negative repercussions considering all dimensions of the environment. By way of carefully pre-planning construction projects, monitoring the effects on biodiversity, implementing pollution-control technologies, implement environmental reverse logistic practices, and usage of multiple product environmental management practices (e.g., cleaner production and eco-labels). A4 and C3 further mentioned that there are conspicuous benefits from the adaptation of the aforementioned environmental management practices in the construction industry, such as contribute to a decrease in consumption of materials, save energy consumption, minimise effluent waste and C&D waste generation, the drawdown of the frequency of environmental accidents and reduce construction and operation costs. Although, S3 insisted that "*there is a net cost growth in the short run in applying environmental management practices as a result of the investment in staff training and use of technology."* In contrast to that, A2 commented that *"proper utilisation of environmental management practices gains financial benefits in a variety of ways, for instance, cost-saving due to fall in fines involved in convictions for environment-related offenses, as a consequence of noncompliance with environmental legislation."* Moreover, S4 and S1 mentioned that positive environmental performance assists organisations in the construction industry to gain a renowned reputation and establish an excellent social image. Moreover, A3 emphasised that *"the implementation of environmental management practices automatically rises overall organisational competitiveness."* From the opinions of all the interviewees, it is very critical to manage the environmental impact in the Sri Lankan construction industry.

4.5 Introducing LCA as an Environmental Management Tool for the Sri Lankan Construction Industry

G3 identified that in response to the local pursuit of environmental sustainability, LCA has been receiving mainstream attention during the past decade. According to respondent A3, "*in the field of ecological design, construction, and operation of infrastructural facilities, the LCA methodology is increasingly regarded as an important decision support tool."* Respondent further mentioned that this is mainly due to the advantages of implementing LCA as a salient decision-support tool. C2 stated that "*LCA aid decision-makers recognise the major impacts of construction and take actions to initiate eco-friendly construction plans at the early stages of construction. Besides, LCA makes a framework for managing possible ecological impacts without compromising the company's corporate goals because it helps to achieve marketing advantages, reduce costs, and improve relationships with governments, communities, and local authorities"*. As efforts to achieve sustainability in the construction industry, all five (05) contenders are increasingly concerned about incorporating the LCA concept into construction decisions.

All interviewees agreed that the LCA is still a relatively new concept for the Sri Lankan construction industry, and it is still receiving insufficient attention. The establishment of LCA in the Sri Lankan construction industry is the collective effort, and it is a shared responsibility of five (05) contenders. Almost all of the interviewees agreed that the objective of LCA implantation to the Sri Lankan construction industry could not be achieved without contributing efforts by the entire society, including the contenders, e.g., academia, government, construction industry, society, and environmentalists. According to A1, A2, C1, and G3, academia should contribute to the establishment of LCA by expanding and deepening research activities on LCA. G1, G3, S1, and C3 stated that the government should establish a useful regulatory framework to ensure ecological-sensitive construction practices with the use of LCA principles. According to C1 and C3, stakeholders in the construction industry should increase their interest to implement LCA as a decision-making tool. According to S1, "*NGOs should conduct programs to improve* *stakeholders' awareness on LCA application."* As per the opinion of S2 and S3, the fifth contender of environmentalists should educate the entire society about sustainable initiatives and financial benefits that could experience with the use of LCA.

4.6 Strengths/Opportunities and Weaknesses/Threats for Establishing Life Cycle Assessment in the Sri Lankan Construction Industry

Recognised positive factors (refer Table 2.1) from the literature synthesis were presented to interviewees from each contender (e.g., academia, government, construction industry, society, and environmentalists) for evaluating their relative importance (from an internal perspective versus an external perspective). Repertory grid interviews were conducted to evaluate the positive factors. Interviewees were requested to indicate the importance of each of the positive factors by selecting any one of the five categories; namely, category I being 'not important' and category V being the 'most important' positive factors. Furthermore, the middle categories II, III, and IV respectively indicated 'less important,' 'neutral,' and 'important' positive factors for establishing LCA in the construction industry.

Similarly, negative factors identified from the literature synthesis (refer Table 2.2) were presented to respondents from each contender (e.g., academia, government, construction industry, society, and environmentalists) to evaluate their level of influence (from an internal perspective versus an external perspective). Repertory grid interviews were conducted to evaluate the negative factors for establishing LCA in the Sri Lankan construction industry. Interviewees were requested to indicate the level of influence for each negative factors by selecting any one of the five categories, namely, category I being 'not influential,' category V being 'extremely influential.' Furthermore, the middle categories II, III, and IV respectively indicated 'slightly influential,' 'neutral,' and 'influential' negative factors in establishing LCA in the construction industry.

Moreover, respondents were asked to add additional positive and negative factors other than the literature findings. Subsequent sections present the findings for the contenders;

academia, government, construction industry, society, and environmentalists, respectively.

4.8 Contenders in the Quintuple Helix Innovation Model: Academia

The following sections present the evaluation results of the academic community's strengths/opportunities and weaknesses/threats in establishing LCA in the Sri Lankan construction industry. Further, the identified positive factors and negative factors were evaluated from an internal perspective against the external perspective with the use of the repertory grid interview technique to identify strengths/opportunities and weaknesses/threats separately. Then, two repertory grids were developed and SWOT analysis was developed with the use of findings derived from the repertory grids. Finally, strategies to overcome weaknesses and threats in establishing LCA in the construction industry were identified.

4.8.1 Strengths and Opportunities in Establishing LCA in the Construction Industry: Academia

The following section presents the developed repertory grid for the strengths and opportunities encountered by academia when establishing LCA in the Sri Lankan construction industry.

Table 4.1: Repertory Grid for the Strengths and Opportunities in Establishing LCA in the Sri Lankan Construction Industry: Academia

Internal Perspective						**External Perspective**				
I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important					**Positive Factors**	**I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Strengths					
					I. Ability to identify opportunities for environmental improvements					
					II. Ability to develop LCA–based benchmarks (e.g., energy consumption)					

III. Use of LCA to develop eco-labeling criteria and EPDs for communication purposes
IV. The ability to use LCA as a novel approach for R&D
V. The ability to introduce environmental policies by incorporating LCA
Opportunities
VI. Empirically proved benefits of conducting LCA
VII. Positive growth in the country to achieve environmental sustainability
VIII. The availability of LCA software packages
IX. The availability of standardise LCA guides and handbooks
X. Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA
Rejected Strengths and Opportunities
XI. Use of Building Information Modeling (BIM) with LCA tools
XII. Ability to obtain marketing benefits

Number of respondents agreed to the statement out of four	**Color Code**
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4.1, all interviewees assessed the relative importance of strengths and opportunities concerning internal and external perspectives. Findings highlighted that ‘ability to identify opportunities for environmental improvements,’, ‘ability to develop LCA–based benchmarks’, ‘use of LCA to develop eco-labeling criteria and EPDs for communication purposes’, ‘ the ability to use LCA as a novel approach for R&D’ and ‘the ability to introduce environmental policies by incorporating LCA’ are classified as strengths. Concerning the strength of ‘identify opportunities for environmental improvements’, A1 stated that *“LCA was conducted to evaluate the embodied carbon* *emission in the Sri Lankan office building, focusing on the material extraction and production phase. The study identified that the clay bricks and reinforced concrete are the key carbon-emitting building materials that contribute to over 70% of the entire embodied carbon emission. The results of the study highlighted that the selection of building materials, especially high carbon-emitting material, should receive greater attention"*. Concerning the one of another strength of 'ability to develop LCA–based benchmarks,' A2 emphasised that benchmarking is an effective analysis method that supports to improve performance (e.g., operational, environmental, etc.) in many fields for different purposes. For instance, A1 stated that *"LCA-based benchmarks have been utilised by the academics in their researches to compare the building's energetic performance to determine whether the performance of a particular type building (e.g., residential, commercial, or industrial) is good, average, or poor compared to other buildings of the same type."*

'The ability to use LCA as a novel approach for R&D' is also considered as a strength for academia. A4 highlighted that *"with a rising interest in environmental concerns to assess the environmental impacts of mega construction projects (e.g., Mega Polis and Western Region Development Project) in Sri Lanka has become an increasingly paramount issue. Use of LCA as a novel approach to address these deficits is being pioneered by academics."* A2 and A3 stated that when considering the strength of 'the ability to introduce environmental policies by incorporating LCA' claimed as an extremely important and important strength. As pointed out by A3, *"it could not be identified that LCA incorporated public policies or legislation in Sri Lanka. Nevertheless, the LCA has potential applications in the development of public policies to determine opportunities for ecological improvement and evaluate environmental trade-offs amongst potential alternatives. Hence, currently, academia is being taken initiatives to develop the product-related environmental policy frameworks (e.g., Eco-labeling, environmentally responsible public procurement, and sustainable consumption and production) by incorporating life cycle thinking.*

Moreover, ‘empirically proved benefits of conducting LCA’, ‘positive growth in the country to achieve environmental sustainability’, ‘the availability of LCA software packages’, ‘the availability of LCA standardise LCA guides and handbooks’ and ‘availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA’ identified as opportunities for the academia in establishing LCA in the Sri Lankan construction industry.

Concerning the opportunity of ‘positive growth in the country to achieve environmental sustainability,’ A1 stated that *“the rapid growth in unsustainable construction practices has brought an enormous burden on scarce resources and the environment. Therefore, academics are taking initiatives to identify methodologies to address unmanageable environmental issues with the use of LCA”*. A4 further mentioned that “*there is an agreement that further environmental degradation should be completely and effectively managed. Consequently, academia contributes their effort by doing LCA related research activities to explore innovative building construction techniques to limit environmental disruption and to use resources effectively, efficiently, and economically*”.

‘The ability to use LCA software packages’ identified as an extremely important and important opportunity for academia. According to A2, *“LCA software packages are widely available, either freeware or shareware. Freeware is easily accessible with no cost, and shareware is available with a purchase or subscription fee. Both of these tools are straightforward to use, though some training is required for the user to become proficient in using them”*. Accordingly, all academics claim that ‘the availability of software packages’ is an opportunity for them.

Most of the interviewees stated that ‘ability to obtain marketing benefits’ and ‘use of BIM with LCA tools’ as less important and not important for both perspectives. A1 and A2 expressed that LCA could be used to demonstrate the companies' contribution towards environmental sustainability, and it could be utilised as a decision-marketing tool to raise market share and to differentiate the companies from its competitors. However, LCA has not been used as a marketing tool in Sri Lanka.

4.8.2 Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Academia

The following section presents the developed repertory grid for the weaknesses and threats encountered by academia when establishing LCA in the Sri Lankan construction industry.

Table 4.2: Repertory Grid for the Weaknesses and Threats in Establishing LCA in the Sri Lankan Construction Industry: Academia

Internal Perspective						**External Perspective**				
I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential					**Negative Factors**	**I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Weaknesses					
					I. Unavailability of experienced LCA professionals					
					II. LCA for the buildings are more complex than LCA for conventional products					
					Threats					
					III. Unavailability of accurate LCA data					
					IV. Limited availability of platforms to publicise the LCA concept					
					Rejected Weaknesses and Threats					
					V. The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)					
					VI. Limited awareness of LCA as a decision-making tool to assess environmental performances within the construction industry					
					VII. Problems in credibility and understanding of LCA results					
					VIII. Absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA					
					IX. Lack of favorable governmental incentives					

	X. Non-integration of LCA with building management software (e.g. Building Information Modeling)			
	XI. Lack of appreciation for the application of LCA			

Number of interviewees agreed to the statement out of four	**Color Code**
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4.2, 'unavailability of experienced LCA professionals' and 'LCA for the buildings are more complex than LCA for conventional products,' identified as weaknesses in establishing LCA in the construction industry. A3 highlighted that the *"unavailability of experienced LCA professionals is not an extremely influential weakness for academia as the number of LCA professionals in Sri Lanka remains insufficient to meet local needs."* 'LCA for the buildings are more complex than LCA for conventional products' identified as extremely influential threats for academia. A1 expressed that LCA on the building would be complicated as each building is unique in its type. Moreover, A2 stated that *"due to the complexity of buildings and other forms of structures with a long service life (usually more than 50 years), the application of LCA in the construction field has become complex, and it is difficult to predict the potential environmental impact from the cradle to the grave. Also, the building may undergo several changes and modifications to its structure during its life cycle, which makes its assessment more complicated"*.

'Unavailability of accurate LCA data' and 'limited availability of platforms to publicise LCA concepts' were identified as threats for academia. According to A3 and A4, gathering accurate data to conduct LCA of buildings in Sri Lanka is a real daunting task. A3 stated that *"due to the nature of the ineffective record-keeping practices adopted by the construction industry, there are problems with gathering accurate and complete primary LCA data."* Concerning the 'limited availability of platforms to publicise LCA concept' A1 stated that *"few researchers in Sri Lanka are engaged in LCA-related research activities. However, Sri Lanka does not have an effective knowledge dissemination platform or network; hence, the results of these studies could not be used meaningfully and categorised this threat as highly influential for academia.*

Concerning the 'the high cost of performing LCA,' A2 explained that *"LCA is data-intensive and requiring a group of diverse experts working collaboratively. However, from an academic point of view, the universities consist of resources such as multi-user LCA software and LCA experts, which makes this slightly influential weakness".* Considering the 'absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA, A3, and A2 stated that in Sri Lanka, regulations or policies specifically meant for the implementation of LCA for the construction industry had not been made available. Further to A3, the government has the responsibility to promote the LCA by formulating policies, regulations, and competent authorities. However, most of the interviewees in the opinion that LCA could be identified as a voluntary approach, and it is not necessary to have a regulatory background to implement LCA and identified as a neutral threat for the academia. Figure 4.1 presents the SWOT analysis, which was developed with the use of findings derived from the repertory grids presented in (Table 4.1 and Table 4.2).

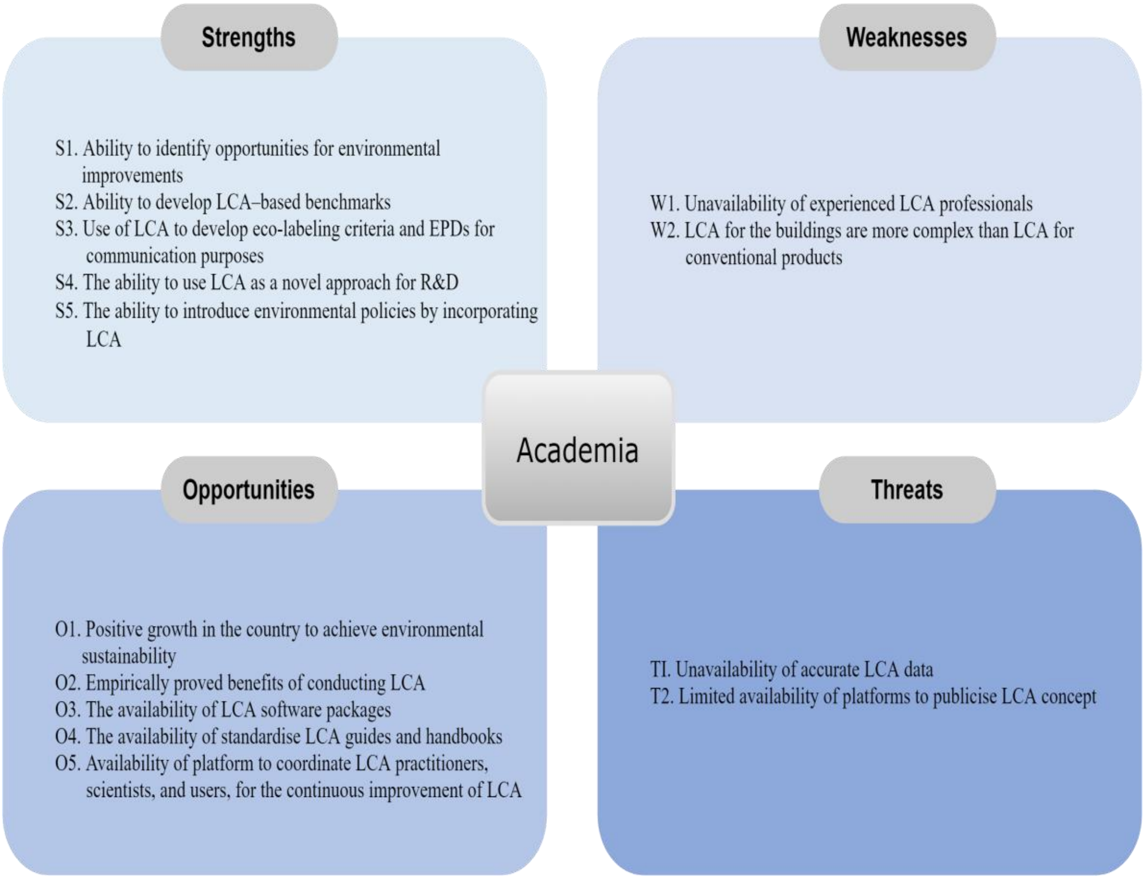

Figure 4.1: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Academic Perspective

4.8.3 Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Academia

Although the weaknesses and threats that emerged during the application of LCA for the construction industry in Sri Lanka could be overcome by applying certain strategies. Hence, it was required to determine the strategies to enhance the application of LCA. Table 4.3 is presented the appropriate strategies recommended by the interviewees representing five (05) contenders to enhance the LCA application in Sri Lanka.

Table 4.3: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Academia

Respondent ID	Recommended Strategy	Target Weaknesses and Threats
A3 and A1	**SA1. Contribute to the knowledge production and implementation of LCA by expanding and deepening research activities** LCA was found to be an innovative method that could be used to improve the environmental sustainability of the construction sector. LCA aims to determine the dynamic and complex interactions between environmental depletion and construction activities. LCA could be used to formulate strategies to decrease resource consumption, waste generation, environmental loads, and further LCA recommends strategies such as reuse and recycling of construction materials. Therefore, research activities in the field of LCA should be used to enhance the effectiveness and efficiency of construction activities while reducing environmental degradation.	W1, W2 and T1
A1	**SA2. Drew up an action plan to incorporate LCA literacy to undergraduate and post-graduate programs** Currently, some university courses cover areas related to LCA. Nevertheless, their depth of coverage is insufficient to provide a comprehensive knowledge base for the practical application of LCA. Most courses provide an introductory level of knowledge. Therefore, reorganising mainstream education programs by combining concepts related to environmental sustainability and LCA into related subject areas provides students with tremendous opportunities to enable them to face a changing, complex and uncertain future as a skilled decision-maker.	W1 and W2
A3 and A4	**SA3. Encourage government bodies to combine LCA with environmental policies to establishing environmental sustainability in the construction industry** The coherent policy framework shows a series of coordinated actions that support companies to establish sustainability initiatives	T1
A1 and A4	**SA4. Maintain relationships with government and construction industries to use the LCA concept to promote innovation-driven environmental sustainability practices** Help to the government and the construction industry to achieve environmental sustainability through LCA consulting, deliver of human capital by way of graduates who aware about the LCA concept, and publishes LCA results through conferences and journal papers to make accurate decisions and promote to use LCA for environmental communication	W1, W2 and T1

A4	**SA5. The development of a standardised buildings LCA framework for Sri Lanka which is essential to increase the consistency and accuracy of the LCA establishment**	W2
G1, G2, G3, and G4	**SG3. Provide funding for research and development activities on LCA and database development activities**	W1, W2 and T1
A1, A4, G2, C3, C4, S1, S3 and E3	**C1. Promote multi-stakeholder and cross-sector collaborations by establishing a network or platform to gather research bodies, government bodies, LCA professionals, environmentalists, and representatives from NGOs** The multi-stakeholder collaborations enable the above stakeholders to work together in an innovative way to generate new possibilities to promote the application of LCA in the Sri Lankan construction industry. These could be identified as the best way to disseminate knowledge between different stakeholders.	T1, and T2
A1, A2, G1, C1, C4, S1, S3, E3 and E4	**C2. Actively participate in the development of LCA database** The accuracy and reliability of the conclusions drawn by the LCA study depend on the relevance and credibility of the data used for analysis. Currently, most LCA studies are conducted by obtaining data from databases developed in European countries, so the conclusions of these studies may be misleading. Therefore, action needs to be taken to develop a user-friendly LCA database for commonly used data categories (such as transportation, building materials, and utilities, such as electricity, fuel, and water). Representatives of government agencies, academia, construction industry associations, and NGOs must work together to develop the LCA database.	T1
A2, G3, C2, C3, S1, S3, E1 and E3	**C3. Take actions to make the people aware about the LCA concept** Academia could actively participate in educating, training, and motivating the use of the LCA concept. Informational and inspiring seminars, publishing books, and brochures are just some tools that could be used to promote LCA. Awareness programs could be conducted by selecting representatives from the government and construction industry, and then they could use their knowledge to promote these concepts.	W1 and W2
A1, A2, G2, C1, S3, S4, E3	**C4. Use LCA for environmental communication**	T1

4.9 Contenders in the Quintuple Helix Innovation Model: Government

The following sections present the evaluation results of the government strengths/opportunities and weaknesses/threats in establishing LCA in the Sri Lankan construction industry. Further, the identified positive factors and negative factors were evaluated from an internal perspective against the external perspective with the use of the repertory grid interview technique to identify strengths/opportunities and weaknesses/threats separately. Then, two repertory grids were developed and SWOT analysis was developed with the use of findings derived from the repertory grids. Finally, strategies to overcome weaknesses and threats in establishing LCA in the construction industry were identified.

4.9.1 Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Government

The following section presents the developed repertory grid for the strengths and opportunities encountered by the government when establishing LCA in the Sri Lankan construction industry.

Table 4.4: Repertory Grid for the Strengths and Opportunities for Establishing LCA in the Sri Lankan Construction Industry: Government

Internal Perspective						**External Perspective**				
I=Not Important **II=Less Important** **III= Neutral** **IV = Important** **V=Extremely Important**					**Positive Factors**	**I=Not Important** **II=Less Important** **III= Neutral** **IV = Important** **V=Extremely Important**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Strengths					
					I. Ability to identify opportunities for environmental improvements					
					II. Ability to develop LCA–based benchmarks (e.g. energy consumption)					
					III. Use of LCA to develop eco-labeling criteria and EPDs for communication purposes					
					IV. The ability to use LCA as a novel approach for R&D					
					V. The ability to introduce environmental policies by incorporating LCA					
					Opportunities					
					VI. Positive growth in the country to achieve environmental sustainability					

VII.	Empirically proved benefits of conducting LCA
VIII.	The availability of LCA software packages
IX.	The availability of standardise LCA guidelines and handbooks
Rejected Strengths and Opportunities	
X.	Ability to obtain marketing benefits
XI.	Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA
XII.	Use of Building Information Modeling (BIM) with LCA tools

Number of interviewees agreed to the statement out of four	Color Code
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4.4, 'ability to identify opportunities for environmental improvements', 'ability to develop LCA–based benchmarks',' 'use of LCA to develop eco-labeling criteria and EPDs for communication purposes', 'the ability to use LCA as a novel approach for R&D' and 'the ability to introduce environmental policies by incorporating LCA' identified as strengths for the academia. For instance, G1 stated that *"the government of Sri Lanka was used LCA for the development of Sustainable Consumption and Production (SCP) policies."* G2 and G1 implied that SCP is a holistic approach associated with a life cycle perspective that aims to reduce the environmental impact of consumption and production decisions. According to G3, enforcement of SCP policies with the inclusion of LCA offers effective and transparent opportunities for environmental improvements. Accordingly, the 'ability to identify opportunities for environmental improvements' could be identified as a strength. From a government point of view, another extremely important strength is the ‘ability to develop LCA–based benchmarks.’ For example, in the opinion of G1, *“the National Energy Management Plan (EnMAP) was implemented by the Sri Lankan Sustainable Energy Authority (SLSEA) as the governing body that is responsible for leading the sustainable energy revolution in the country. As a part of EnMAP, energy benchmarks were established by SLSEA to measure the energy-saving potential of several industries with the use of LCA. Commercial and Industrial sectors, which contributing approximately around 60% of the electricity consumption of Sri Lanka, were selected as the key sectors for developing energy benchmarks. For example, energy consumption benchmarks for commercial buildings are 136.55 kWh/m2.year”*.

‘Ability to use LCA to develop eco-labeling criteria and EPDs for communication purposes’ identified as an extremely important and important strength. In the opinion of G3, *“EPD could be identified as the document containing information about the life cycle environmental impacts of products. However, the Sri Lankan building sector is still lagging in the development of the EPD. Hence, it is difficult to identify EPD certified construction materials in Sri Lanka”.* According to G1 and G3, most of the building materials used in the Sri Lankan construction sector have been imported by other countries. Nevertheless, the government gradually increase their interest in developing LCA based EPD and eco-labels.

‘The ability to use LCA as a novel approach for R&D’ identified as an extremely important strength. As climate change and GHG emissions reduction play an increasingly important role in environmental policy plans, then regulators and policymakers have been looking for existing environmental management tools (such as LCA) to find innovative ways to solve these complex problems, which has become an extremely important strength for the government. ‘The ability to introduce environmental policies by incorporating LCA’ is also an extremely important strength. G1 highlighted that *“recently LCA has included in the environmental policy formulation process to minimise the negative environmental effects associated with construction outputs.”*

Further, ‘positive growth in the construction industry to achieve environmental sustainability’ ‘empirically proved benefits of conducting LCA’, ‘the availability of LCA software packages’, ‘the availability of standardise LCA guidelines and handbooks’ and ‘availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA’ identified as opportunities for the government in establishing LCA. Considering the ‘the availability of LCA software packages’, there are LCA modeling and reporting software such as GaBi, Ecoinvent, Simapro, etc. with intuitive data collection and result analytics capabilities. As pointed out by G3, *“no LCA databases specifically developed for the Sri Lankan construction sector. Therefore, secondary data could be taken from external databases to perform LCA easily, which makes this an extremely important opportunity for government”.* When considering the guideline and handbooks, it provides a framework for the implementation of the LCA. According to G2, G3, and G4, the ISO framework is a strong foundation for the LCA implementation process. Therefore, ‘the ability to use standardise LCA guidelines and handbooks’ becomes an extremely important opportunity.

‘Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA’ identified as another opportunity. For instance, National Cleaner Production Centre Sri Lanka (NCPC-SL) could be recognised as one of the not-for-profit organisations that have been taken initiatives to implement LCA within Sri Lanka. For example, G3 highlighted that *“capacity building programs on LCA and eco-design have been conducted with a pioneering contribution from the NCPC-SL.”* The number of professionals, including government representatives, consultants, academics, researchers, and industrialists, was trained and given hands-on experience on LCA software, which made this opportunity extremely important and important for both perspectives.

Moreover, ‘ability to obtain marketing benefits’ and ‘use of BIM with LCA tools’ identified as less important for the Sri Lankan context. Many stakeholders in the construction industry in developed countries are incorporating LCA into their construction projects. Contractors could use accurate LCA-based information to leverage sustainability decisions. For example, According to G3, *"a contractor who used LCA as a decision-making tool could use LCA results to compare environmental impacts with conventional buildings. Therefore, LCA-based information could support mainstream marketing platforms by proclaiming advantages over conventional buildings"*. Nevertheless, G4 highlighted that Sri Lanka does not use LCA-based information to reap marketing benefits. Hence, this identified as a less important strength. When considering the 'use of BIM with LCA tools'. G2 stated that the decision-making process could be empowered with the integration of BIM with LCA at an early stage of construction projects. BIM offers architects, consultants, designers, engineers, etc. with precise data needed to assess the environmental impacts in the construction projects over the entire lifecycle. There is increasing concern about the integration of BIM and LCA to simplify effective, accurate, and fast decision-making in construction projects in the early planning stages of developed countries, but on the contrary, in Sri Lanka, this is lacking in the current situation and identifies this opportunity as a neutral and less important.

4.9.2 Weaknesses and Threats in Establishing Life Cycle Assessment for the Construction Industry: Government

The following section presents the developed repertory grid for the weaknesses and threats encountered by the government when establishing LCA in the Sri Lankan construction industry.

Table 4.5: Weaknesses and Threats in Establishing LCA for in Construction Industry: Government

Internal Perspective						**External Perspective**				
I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential					**Negative Factors**	**I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Weaknesses					
					I. Unavailability of experienced LCA professionals					

	II. LCA for the buildings are more complex than LCA for conventional products
	III. Limited awareness of LCA as a decision-making tool to assess environmental performances within the construction industry
Threats	
	IV. Unavailability of accurate LCA data
	V. Lack of appreciation for the application of LCA
	VI. Limited availability of platforms to publicise LCA concept
Rejected Weaknesses and Threats	
	VII. The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)
	VIII. Problems in credibility and understanding of LCA results
	IX. Lack of favorable governmental incentives
	X. Absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA
	XI. Non-integration of LCA with building management software (e.g. Building Information Modeling)
Newly added Threats	
	XII. Absence of a perceived need for LCA

Number of interviewees agreed to the statement out of four	Color Code
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4.5, most of the interviewees agreed that ‘unavailability of experienced LCA professionals, ‘LCA for the buildings are more complex than LCA for conventional products’ and ‘limited awareness on LCA’ are weaknesses for the government. G1 emphasised that *“the lack of LCA expertise and technical know-how is an extremely influential weakness to establish LCA.”* According to G2 and G4, lack of knowledge and stakeholder awareness of LCA as an environmental assessment tool is another long-standing weakness. Most of the interviewees mentioned that this was due to the lack of tailor-made training in environmental management, as well as to the shortcomings in Sri Lanka's education system (e.g., sustainability education is not properly integrated into academic studies).

As per G1, G2 and G3 buildings are highly multi-functional, and the life expectancy of a building is very long. Hence it is difficult to assess, which causes an imprecision. For instance, according to G1, *“the composition of building components and materials are heterogeneous, and energy efficiency and energy sources may change from time to time. Therefore the predictions of environmental impacts could not be accurate”*. Therefore, all interviewees collectively believed that ‘LCA of the building is more complicated than the LCA of the product’ was a highly influential weakness.

‘The high cost of performing LCA’ is considered a slightly influential weakness. G3 highlighted that *“LCA could be identified as an important tool that coherently contributes to science-based decision-making. Thus it becomes an obstacle due to the associated high implementation costs”*. According to G1, introducing LCA necessitates companies to purchase the pertinent software and must pay for LCA experts. The highest front-end cost of introducing LCA is seen as an extremely influential threat to uptake LCA within the construction sector. But conversely, G2 and G4 stated that this is a slightly influential or not influential weakness to the government due to the availability of sufficient funds and software packages for government use. Considering the ‘lack of favorable governmental incentives’ as pointed out by G3, *“government-funded construction projects have allocated sufficient funds to incorporate life cycle thinking principles to mitigate the environmental impact hence become this weakness neutral.*

Moreover, ‘unavailability of accurate LCA data’, ‘ lack of appreciation for the application of LCA’, and ‘limited availability of platforms to publicise LCA concept’ identified as threats in establishing LCA in the construction industry. Considering the "unavailability of accurate LCA data’ G3 and G4 explained that due to the unavailability of the LCA database designed for the Sri Lankan construction sector, collecting raw data has become a challenge. Considering the threat of 'the lack of appreciation of the application of LCA,' G3 stated that most countries in Europe had launched award schemes to recognise the organisation's outstanding contributions in promoting LCA and life cycle thinking. In contrast, GI asserted that *"in Sri Lanka, there is no appreciation for individuals and organisations that have demonstrated excellent service in applying life cycle thinking and LCA."* Therefore, "the lack of appreciation for the application of LCA" was criticised as an influential threat. Considering the threat of "limited availability of platforms to publicise LCA concept" could be identified as one of another highly influential threat. G2 and G4 explained that Life Cycle Assessment for Design Sustainability Network (LCADeSNet) had been done tremendous work to promote LCA in Sri Lanka. However, G1 added that *"restrictions faced by LCADeSNet, such as lack of government recognition, authority, and other restrictions, that handicaps the activities taken by this organisation."*

According to G2 and G4 local authorities and government are currently revising environmental regulations, and professional institutions such as GBCSL have introduced guidelines related to sustainable construction practices based on life cycle thinking. As pointed out by G2, *"with the release of environmental regulations and guidelines, it is expected that developers start to pursue environmentally friendly construction practices, thereby indirectly assisting the Sri Lankan construction industry in establishing LCA. When developers are interested in complying with environmental policies, the rest of the stakeholders in the construction industry also be pulled towards this direction."* G3 further explained that *"the Ministry of Environment and Natural Resources is the key policy development body for the environmental sector in Sri Lanka. The country's environmental management has been supervised by the Central Environment Agency (CEA). The government of Sri Lankan has issued policies that indirectly drive the implementation of life cycle thinking in the construction industry, such as the National Energy Policy (2003), National Environmental Policy (2003), National Climate Change Policy (2011), Cleaner Production Policy (2004), etc."* Therefore, the 'absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA' has become a neutral opportunity.

Currently, in some developed countries, there is a trend of integrating BIM with LCA to accurately assess the environmental impact of the building life cycle at the early planning stages. However, in Sri Lanka, the application of BIM and LCA is still very primitive. Therefore, the construction industry in Sri Lanka is trying to implement LCA, and this innovation is not timely essential and identified as neutral. Further interview findings revealed the 'absence of a perceived need for LCA' as another threat due to the lack of supply chain management responsibility and environmental awareness, and stakeholders are less likely to demand LCA. Therefore, it could be seen that the application of LCA was further threatened by the lack of commitment of top management for LCA.

Figure 4.2 presents the SWOT analysis, which was developed with the use of findings derived from the repertory grids presented in (Table 4.4 and Table 4.5).

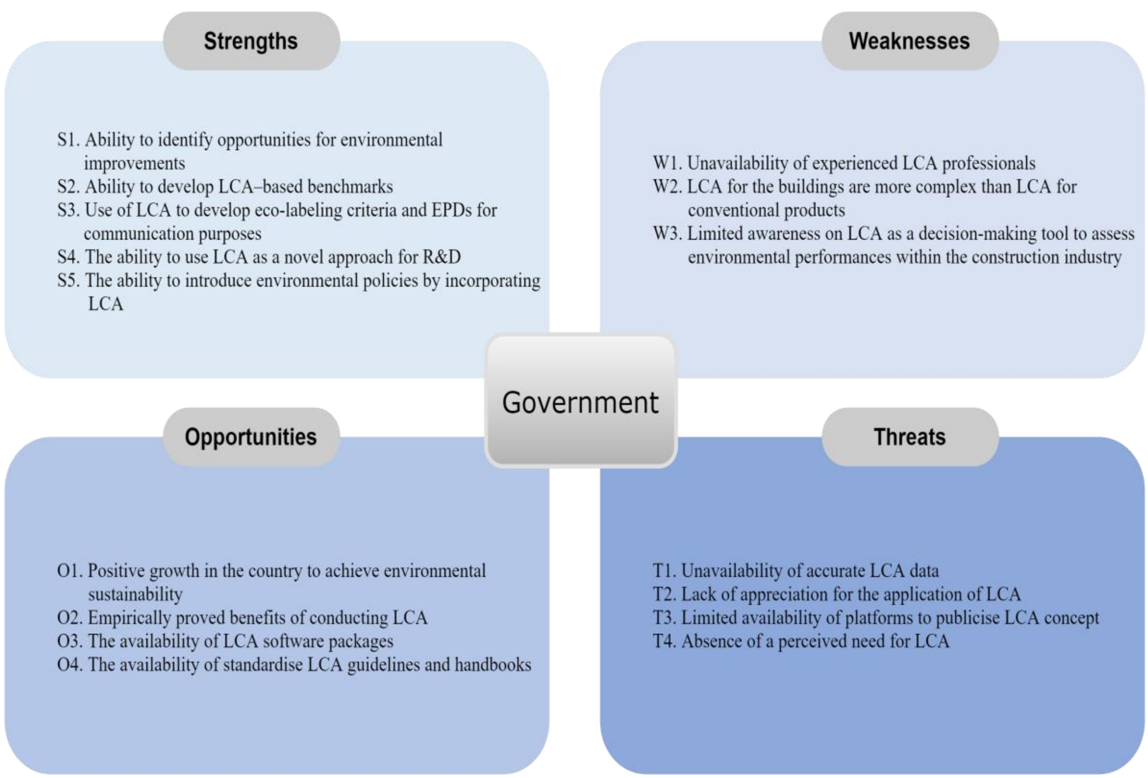

Figure 4.2: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from the Government Perspective

4.9.3 Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Government

The identified weaknesses and threats indicate that the application of LCA in the construction industry in Sri Lanka is limited. Hence Table 4.6 introduced strategies to overcome weaknesses and threats in establishing LCA in the construction industry.

Table 4.6: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Government

Respondent ID	Recommended Strategy	Target Weaknesses and Threats
G2	**SG1. Government intervention by providing financial incentives** LCA is fairly novel to the Sri Lankan construction industry, and the application of LCA is gradually increasing. The profit-driven culture of the construction industry demotivates to apply LCA. Financial mechanisms could motivate stakeholders in the construction industry to adopt LCA. Financial incentives such as tax rebates, green loan schemes, and subsidies could alleviate the high cost associated with LCA application. It is also essential to provide financial support to establish an LCA laboratory in Sri Lanka, LCA practitioners could use the LCA laboratory to conduct LCA related research activities, and the laboratory should be facilitated through multi-user LAC software packages and other related databases.	T1
G1 and G3	**SG2. Take initiatives to establish responsible organisations to promote the application of LCA** Currently, it could be seen as a fairly less institutional intervention to promote LCA as a decision-making tool. Taking leadership to strengthen sustainable construction practices with the help of LCA could be improved by establishing more socially responsible organisations like NCPC and GBCSL to make the people aware about the LCA concept.	W3, T3, and T4
G1, G2, G3, and G4	**SG3. Provide funding for research and development activities on LCA and database development activities** Provide financial support for LCA-based research, and provide funds for government agencies and universities to purchase multi-user LCA software packages. Software packages such as Simapro, Umberto, and GaBI could be identified as some of the commercial software packages	W1, W3, and T1

	available for LCA. But, the cost of purchasing the software, as mentioned above, is more expensive, except that the necessary funds are provided through research grants or any other mechanisms.	
G4 and G2	**SG4. Use LCA principles to establish an effective regulatory framework to ensure ecologically sensitive construction practices** The government plays a prominent role in making the essential legal infrastructure to promote the widespread adoption of environmentally friendly building practices. LCA could be used to assist government agencies in formulating policies that may bring long-term environmental benefits. However, current environmental regulations are not excessive. Therefore, it is necessary to formulate appropriate policies based on the LCA method to improve the county's environmental management practices. Moreover, necessary amendments have to be made for the outdated Ordinances and Acts, which are still governed by the Sri Lankan law.	W3 and T4
G3	**SG5. Appraise the application of LCA for the mega-scale construction projects** The client's enthusiasm for the application of LCA could be increased by introducing award schemes.	T2
G2	**SG6. Develop a building-specific LCA methodology that is currently lacking** At present LCA research is in a state of fragmentation as there are no clear guidelines for the application of LCA in the construction industry	W2
A3 and A1	**SA1. Contribute to the knowledge production and implementation of LCA by expanding and deepening research activities**	W2, W3, and T1
A1, A4, G2, C3, C4, S1, S3 and E3	**C1. Promote multi-stakeholder and cross-sector collaborations by establishing a network or platform to gather research bodies, government bodies, LCA professionals, environmentalists, and representatives from NGOs**	T1, and T3
A1, A2, G1, C1, C4, S1, S3, E3 and E4	**C2. Actively participate in the development of LCA database**	W1, W3, and T1
A2, G3, C2, C3, S1, S3, E1 and E3	**C3. Take actions to make the people aware about the LCA concept**	W1 and W2

A1, A2, G2, C1, S3, S4, E3	**C4. Use LCA for environmental communication**	T1

4.10 Contenders in the Quintuple Helix Innovation Model: Construction Industry

The following sections present the evaluation results of the construction industry's strengths/opportunities and weaknesses/threats in establishing LCA in the Sri Lankan construction industry. Further, the identified positive factors and negative factors were evaluated from an internal perspective against the external perspective with the use of the repertory grid interview technique to identify strengths/opportunities and weaknesses/threats separately. Then, two repertory grids were developed and SWOT analysis was developed with the use of findings derived from the repertory grids. Finally, strategies to overcome weaknesses and threats in establishing LCA in the construction industry were identified.

4.10.1 Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Construction Industry

The following section presents the developed repertory grid for the strengths and opportunities encountered by the construction industry when establishing LCA to the Sri Lankan construction industry.

Table 4.7: Repertory Grid for the Strengths and Opportunities in Establishing LCA in the Sri Lankan Construction Industry: Construction Industry

Internal Perspective						**External Perspective**				
I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important					**Positive Factors**	**I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Strengths					
					I. Ability to identify opportunities for environmental improvements					

	Yellow	Yellow	II. Ability to develop LCA–based benchmarks (e.g., energy consumption)			
Peach	Yellow	Peach	III. Use of LCA to develop eco-labeling criteria and EPDs for communication purposes			
Peach	Yellow	Peach	IV. The ability to use LCA as a novel approach for R&D			
	Blue	Peach	V. The ability to introduce environmental policies by incorporating LCA			
			Opportunities			
			VI. Positive growth in the country to achieve environmental sustainability	Green		
			VII. Empirically proved benefits of conducting LCA	Green		
			VIII. The availability of LCA software packages	Green		
			IX. The availability of standardise LCA guides and handbooks	Green		
			X. Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA	Peach	Yellow	Peach
			Rejected Strengths and Opportunities			
Blue	Peach		XI. Ability to obtain marketing benefits			
			XII. Use of Building Information Modeling (BIM) with LCA tools			Green
			Newly Added Strengths and Opportunities			
			XIII. Growing interest to apply LCA to the construction industry			

Number of interviewees agreed to the statement out of four	**Color Code**
One out of four (1/4)	Peach
Two out of four (2/4)	Yellow
Three out of four (3/4)	Blue
Four out of four (All)	Green

According to Table 4.7, findings highlighted that 'ability to identify opportunities for environmental improvements,' 'ability to develop LCA–based benchmarks,' 'use of LCA to develop eco-labeling criteria and EPDs for communication purposes,' 'the ability to use LCA as a novel approach for R&D,' and 'the ability to introduce environmental policies by incorporating LCA, were classified as strengths. Views regard to ‘ability to identify opportunities for environmental improvements’ were classified as an extremely important strength. C1 commented that *“LCA has gradually played a strategic role in identifying the potential impact of the proposed construction project to support the determination of appropriate strategies to minimise environmental impact and confirms its environmental effectiveness by considering WLC.”* Interviewee’s views on "the ability to develop LCA-based benchmarks" fluctuate between the extremely important and important strength for the construction industry. C4 explained, *“the construction industry needs a powerful mechanism to collect project-level performance information.”* According to C2, benchmarks use as a mechanism to provide a reliable and transparent yardstick to improve the performance of the construction industry. For example, C4 stated that *“the LCA results could be used as a benchmark to compare the average waste generation between construction projects to understand the effectiveness of waste management practices, thereby calculating the Cubic Meters (m^3) of C&D waste each month. Then benchmark could be used to improve C&D waste management practices.”*

Interviewees were identified ‘ability to use LCA to develop eco-labeling and EPDs’ as an extremely important and important strength. C3 indicated that the *“Green Building Council, Sri Lanka (GBCSL) aims to integrate green building practices to the construction sector to ensure environmental conservation. Then, the GBCSL developed a Green Rating System to certify the operations and maintenance of existing buildings. The Green Rating System is a set of performance standards based on the life cycle thinking to encourage the stakeholders in the construction industry to construct the buildings (e.g., commercial, residential, and industrial) in a manner that is compatible with the environment”*. The majority of the interviewees considered ‘the ability to use LCA as a novel approach for R&D’ as an important strength. C4 noted that *“raising environmental awareness has drawn the attention of construction professionals to the use of environmental management tools. As a result, the LCA has been recognised as one of the environmental management assessments for finding new and innovative ways to reduce environmental impact.”* Considering the ‘the ability to introduce environmental policies by incorporating LCA’

C1 stated that *"LCA could link with a policy-making process to maintain an appropriate balance between environmental and economic considerations. Integrating LCA into prevailing policies has the potential to grow its rigor and value."* Therefore, it is defined as an extremely important and important strength.

Although C3 pointed out that the application of LCA in Sri Lanka is at a very primitive level, there is a very limited number of research groups involved in LCA-related research, and 'the ability to use LCA as a novel approach for R&D' become neutral strength. 'Positive growth in the country to achieve environmental sustainability', 'empirically proved benefits of conducting LCA', 'the availability of LCA software packages', the availability of standardise LCA guides and handbooks, and 'availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA' identified as opportunities in establishing LCA in the construction industry. Considering the "positive growth in the construction industry to achieve environmental sustainability "it is identified as an extremely important opportunity. C1, C2, and C4 explained that Sri Lanka had been created a tremendous impact on the environment. Further, the construction industry needs to inevitably alter construction methods that rarely consider the ecological impact, with novel methods focuses on environmental factors. Then, more and more people realise the importance of improving traditional construction practices into a new philosophy, called sustainable construction practices. Then, C3 opined that *"gradually, LCA has begun to ensure the environmental sustainability of the proposed construction project and become an extremely important opportunity. However, the application of LCA in Sri Lanka's construction projects is still an elementary stage."*

According to C3 and C4, 'empirically proved benefits of conducting LCA' could be identified as an extremely important opportunity as it motivates potential stakeholders to conduct LCA. One of the other extremely important opportunities is "using the LCA software package." Using LCA software specifically developed for the construction industry assist in completing the LCA quickly. C2 expressed that *"Gabi, Umberto, and*

Simapro require a high level of knowledge to work. Besides, software such as CAALA, 360 Optimi, and eLCA do not require high levels of knowledge". However, there is problematic to use these software packages due to the high purchasing cost and unfamiliarity. Moreover, 'the ability to use standard LCA guidelines and manuals' is an extremely important opportunity. For example, according to C3, *"ISO 14041-14043 standards guided the implementation of LCA and made the implementation process understandable to both professionals and new users. Therefore, it is very helpful to apply LCA"*. One of the other extremely important and important opportunities is 'availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA.' For example, C1 and C4 noted that the LCADeSNet was organised a capacity building workshop on LCA with the support of the Ministry of Mahaweli Development and Environment (MoMDE). The objective of the workshop was to promote LCA as a decision-making tool in Sri Lanka by increasing the level of awareness among several stakeholders in the education sector, the construction industry, and the state.

According to C1 and C4, currently, most consumers in the construction industry in developed countries are concerned about the social and environmental impact of building materials, and they are willing to purchase green products. LCA is used as a marketing tool to communicate the positive environmental attributes of products to consumers. C1 mentioned that *"unfortunately, the Sri Lankan construction industry has not used LCA as a marketing tool."* Therefore, most of the interviewees rated 'ability to obtain marketing benefits' as a neutral strength. Moreover, the 'use of Building Information Modeling' was identified as a neutral opportunity due to the absence of BIM applications in the Sri Lankan construction industry.

4.10.2 Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Construction Industry

The following section presents the developed repertory grid for the weaknesses and threats encountered by the construction industry when establishing LCA to the Sri Lankan construction industry.

Table 4. 8: Repertory Grid for the Weaknesses and Threats in Establishing LCA in the Sri Lankan Construction Industry: Construction Industry

Internal Perspective I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential					Negative Factors	External Perspective I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Weaknesses					
					I. Unavailability of experienced LCA professionals					
					II. LCA for the buildings are more complex than LCA for conventional products					
					III. The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)					
					IV. Limited awareness of LCA as a decision-making tool to assess environmental performances within the construction industry					
					V. Problems in credibility and understanding of LCA results					
					Threats					
					VI. Unavailability of accurate LCA data					
					VII. Absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA					
					VIII. Lack of favorable governmental incentives					
					IX. Lack of appreciation for the application of LCA					
					X. Limited availability of platforms to publicise LCA concept					
					Rejected Threat					
					XI. Non-integration of LCA with building management software (e.g., Building Information Modeling)					
					Newly Added Weaknesses					
					XII. Insufficient financial gains compared the costs of conducting LCA					
					XIII. Lack of demonstration projects					

Number of interviewees agreed to the statement out of four	Color Code
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to the Table 4.8, 'unavailability of experienced LCA professionals,' 'LCA for the buildings are more complex than LCA for conventional products', 'the high cost of performing LCA,' 'limited awareness of LCA' and 'problems in credibility and understanding of LCA results' identified as weaknesses. Considering the 'unavailability of experienced LCA professionals', almost all interviewees indicated that there is a skills gap between the anticipated level of skills and the real skills possessed by professionals in the construction sector. Therefore, "the unavailability of experienced LCA professionals" indicated an extremely influential weakness. Moreover, C1 noted that *"building construction projects have become progressively more complicated, many construction projects have sophisticated structural systems, use a high degree of mechanical and electrical installations, and serve the diversified needs of different end-users."* Compared with traditional products, evaluating buildings is much more complicated with the available technology. Therefore, 'LCA for the buildings are more complex than LCA for conventional products' identified as an extremely influential weakness. Most of the interviewees perceived that another extremely influential weakness that impedes the widespread application of LCA is the high cost of performing LCA. C1, C2, and C3 declared that the introduction of LCA incurs many costs (e.g., LCA software purchase costs, professional fees of LCA experts) that decrease the interest of contractors in adopting LCA. Conversely, C4 pointed out that *"even with the high cost of establishing the LCA, there were interviewees from well-established companies who were interested in applying LCA, because the implementation of LCA has a beneficial impact, and the cost of implementation could be covered."*

C1 and C3 stated that LCA results are presented with the use of technical language that could not be positively used by decision-makers. If LCA results could not utilise properly, it would stay out of the decision-making process. C1 further stated that *"to embrace the LCA results into the decision making-process LCA results needed to be presented in a comprehensive and targeted manner that could be understood by the decision-makers."* Accordingly, all the interviewees in the collective opinion that, 'problems in credibility and understanding of LCA results' is an extremely influential or influential weakness.

'Unavailability of accurate LCA data', 'absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA', 'lack of favorable governmental incentives', 'lack of appreciation for the application of LCA' and 'limited availability of platforms to publicise LCA concept' identified as threats. Accordingly, the unavailability of accurate LCA data is a very influential threat. According to C1, *"due to the diversity of the construction industry, collection of LCA data is the main practical bottleneck for the establishment of LCA."* When considering other threats of 'absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA', the majority of professionals mentioned that LCA would only be implemented in the construction industry when it is required by legislation or government policy. C4 highlighted that *"the policy background is the key factor in expanding the applications of LCA in the Sri Lankan construction industry.* Although, C2 stated that *"in Sri Lanka integration of LCA to the public policies are very less."* Hence, the 'absence of proper legislative initiatives and competent authorities to encourage the application of LCA' is categorised as an extremely influential threat for the application of LCA.

Concerning the '*lack of favorable governmental incentives,'* there are few numbers of schemes to provide financial assistance in the form of green loans, but these are not sufficient to encourage construction organisations to adopt the LCA. Because C4 stated that the *"profit-driven nature of the construction industry is not interested in applying LCA without some financial incentives, due to the high amount of cost incurred by the implementation of LCA."* Accordingly, 'lack of favorable governmental incentives' identified as an extremely influential threat. Considering another threat of 'lack of appreciation for the application of LCA,' C3 stated that the *"LCA awards scheme should be launched to acknowledges the work done by private companies and academics who have initiated innovative and visionary developments based on the LCA."*

Figure 4.3 presents the SWOT analysis, which was developed with the use of findings derived from the repertory grids presented in (Table 4.7 and Table 4.8).

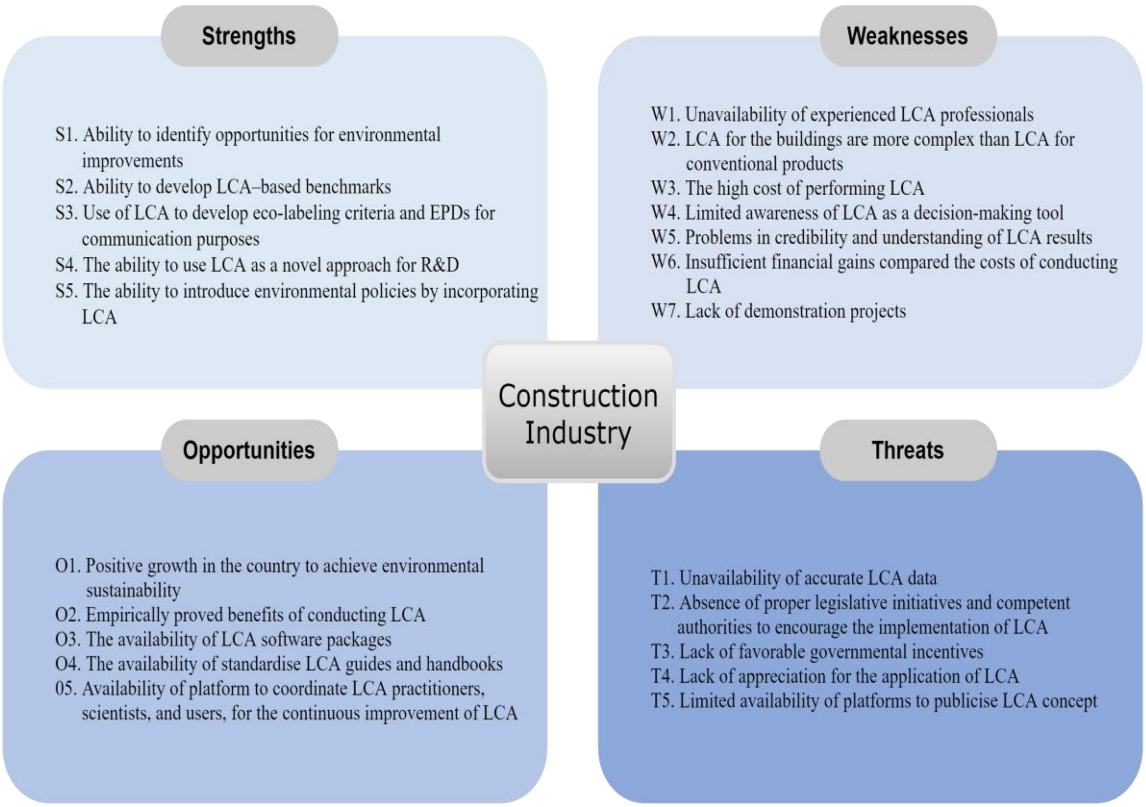

Figure 4.3: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry

4.10.3 Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Construction Industry

Interview findings disclose appropriate and effective strategies to address prevailing weaknesses and threats. Further, Table 4.9 presents the way of addressing weaknesses and threats in Establishing LCA with the use of strategies.

Table 4.9: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Construction Industry

Respondent ID	Recommended Strategy	Target Weaknesses and Threats
C3	**SC1. Use LCA as a prior assessment method to assess negative environmental impacts before starting a construction project** Stakeholders in the construction industry should increase their interest in applying LCA to future construction projects	W7
C3 and C4	**SC2. Stakeholders in the construction industry should use the LCA concept to formulate ecologically sensitive environmental policies** The internal organisational policy could be reformed, redesigned, and reorganised to promote the LCA implementation in the construction industry	W4 and W7
C1	**SC3. Stakeholders including architects, engineers, facility managers, and quantity surveyors should play their due role in providing developers with advice on the advantages of using environmental management tools like LCA** Engineering, architects, consultant, and construction companies should take action to promote environmental sustainability by advising the clients on the importance of implementing environmental management tools and should help to implement environmental management tools. Further, these stakeholders should contribute to the development of LCA database	W1, W2, W4, and W7
C1	**SC4. Implement Total Quality Environmental Management Systems (TQEMS) within the organisation** TQEMS uses LCA as a holistic approach to better understand the relationship between construction activities and the environment. It recognises and considers the ecological costs of environmental inputs and environmental outputs throughout the life cycle. And helps prevent ecological costs from shifting from one medium to another, and from one stage of construction projects to another	W4
C3 and C4	**SC5. The integration of BIM with LCA** The integration of BIM and LCA could accurately assess the environmental impact of the building life cycle at the early stage of the design. BIM could increase transparency and promote collaboration among various stakeholders. Besides, BIM supports multiple analyses and simulations, and the results could then be used to make decisions and ultimately improve the performance of the proposed project. By integrating BIM and LCA, the ability of LCA to enhance environmental performance could be improved	W2, W5, and T1

C2	**SC6. Increase the attention of the construction sector to reduce adverse environmental impacts by using LCA to take decisions** Stakeholders in the construction industry should make efforts to change construction practices. Stakeholders should strive to promote environmentally friendly construction practices. Transform traditional construction practices into environmentally-friendly construction practices with the use of LCA	W5
A1, A4, G2, C3, C4, S1, S3 and E3	**C1. Promote multi-stakeholder and cross-sector collaborations by establishing a network or platform to gather research bodies, government bodies, LCA professionals, environmentalists, and representatives from NGOs**	W1, W2, W5, T5
A1, A2, G1, C1, C4, S1, S3, E3 and E4	**C2. Actively participate in the development of LCA database**	W2, W3, T1
A2, G3, C2, C3, S1, S3, E1 and E3	**C3. Take actions to make the people aware about the LCA concept**	W1, W2, W4, and W5
A1, A2, G2, C1, S3, S4, E3	**C4. Use LCA for environmental communication**	T1
A3 and A1	**SA1. Contribute to the knowledge production and implementation of LCA by expanding and deepening research activities**	W2, T1
G1, G2, G3, and G4	**SG3. Provide funding for research and development activities on LCA and database development activities**	T1
G3	**SG5. Appraise the application of LCA for the mega-scale construction projects**	T4
G2	**SG1. Government intervention by providing financial incentives**	W3 and T3
G4 and G2	**SG4. Use LCA principles to establish an effective regulatory framework to ensure ecologically sensitive construction practices**	T2
S2 and S3	**SS1. NGOs should increase the level of scrutiny over the construction sector regarding the environmental consequences of their activities**	T2
E2	**SE2. Assist in developing a vigorous environmental policy framework and renewed it periodically**	T2
E1, E2, E3 and E4	**SE3. Educate the whole society about sustainable initiatives and the potential financial benefits of using LCA (e.g reducing the cost incurred by minimising material waste, minimising energy use, etc.**	W6

4.11 Contenders in the Quintuple Helix Innovation Model: Society

The following sections present the evaluation results of the society's strengths/opportunities and weaknesses/threats in establishing LCA in the Sri Lankan construction industry. Further, the identified positive factors and negative factors were evaluated from an internal perspective against the external perspective with the use of the repertory grid interview technique to identify strengths/opportunities and weaknesses/threats separately. Then, two repertory grids were developed and SWOT analysis was developed with the use of findings derived from the repertory grids. Finally, strategies to overcome weaknesses and threats in establishing LCA in the construction industry were identified.

4.11.1 Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Society

The following section presents the developed repertory grid for the strengths and opportunities encountered by society when establishing LCA.

Table 4.10: Repertory Grid for the Strengths and Opportunities in establishing LCA in the Sri Lankan Construction Industry: Society

Internal Perspective						**External Perspective**				
I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important					**Positive Factors**	**I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Strengths					
					I. Ability to identify opportunities for environmental improvements					
					II. Ability to develop LCA–based benchmarks (e.g., energy consumption)					
					III. The ability to use LCA as a novel approach for R&D					
					IV. The ability to introduce environmental policies by incorporating LCA					
					Opportunities					

V.	Positive growth in the country to achieve environmental sustainability
VI.	Empirically proved benefits of conducting LCA
VII.	The availability of LCA software packages
VIII.	The availability of standardise LCA guides and handbooks
IX.	Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA
Rejected Strengths and Opportunities	
I.	Use of LCA to develop eco-labeling criteria and EPDs for communication purposes
X.	Ability to obtain marketing benefits
II.	Use of Building Information Modeling (BIM) with LCA tools

Number of interviewees agreed to the statement out of four	Color Code
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4. 10, 'ability to identify opportunities for environmental improvements,' 'ability to develop LCA–based benchmarks' , 'the ability to use LCA as a novel approach for R&D' and 'the ability to introduce environmental policies by incorporating LCA' identified as strengths. S2 pointed out that *"environmental NGOs have been used LCA to calculate environmental impacts in the planning stage of proposed construction projects for determining what changes should be made to reduce the environmental impacts."* Accordingly, the 'ability to identify opportunities for environmental improvements' is become an extremely important strength. The views about 'ability to development LCA-based benchmarking' is varied among extremely important, important, and less important strengths. S1 pointed out that *"Environmental*

NGOs are using benchmarks to creates fertile ground for improvements and to facilitate companies to share best practices and compare their performance with others" Considering the views on 'the ability to use LCA as a novel approach for R&D', to comply with environmental regulations and meet customer needs, environmental NGOs tend to use LCA to identify innovative and novel methods, which made this factor an extremely important for society. Considering one of the other strengths of 'the ability to introduce environmental policies by incorporating LCA', S1 stated that in some developed countries, there are case studies of successful implementation of LCA in environmental policies that provide evidence to encourage decision-makers to incorporate LCA into the public policy development process. Accordingly, environmental NGOs are guiding to incorporate LCA into environmental policies. It proved that the 'ability to introduce environmental policies by incorporating LCA' is an important strength.

S3 noted that *"with the involvement of LCA, several LCA-related applications have emerged, and they used as a basis for communicating the overall environmental performance of products or services to interested parties. Consequently, specific standards have been developed for LCA-based environmental declarations and labels".* ISO divides environmental labels into three types, such as type I (ISO 14021), type II (ISO 14024), and type III (ISO 14025). Each type has specific procedures, and an EPD could be recognised as Class III (ISO 14025). However, according to S1, S3, and S4, practical implementation of these applications in the construction industry is still a problem, and it must be managed to expand its scope of application. Therefore, "the ability to use LCA to develop ecolabel standards and EPD" was considered to be less important and not important for society.

'Positive growth in the country to achieve environmental sustainability', 'empirically proved benefits of conducting LCA', 'the availability of LCA software packages', 'the availability of standardise LCA guides and handbooks' and 'availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA' identified as opportunities. S1, S2, and S3 stated that, in terms of waste generation, environmental pollution, and raw material use, the construction industry is one of the largest contributors in Sri Lanka. As a result, Sri Lanka is increasingly interested in applying ecological innovations based on LCA to reduce its environmental impact. Accordingly, interviewees believed that "positive growth in the construction industry to achieve environmental sustainability" is an extremely important opportunity for society to implement LCA within Sri Lanka. LCA software packages, such as SimaPro, EIO-LCA, GaBi, etc. are widely used to assist the data collection process and also provide a structural modeling framework for LCA. Besides, there are several useful programs for energy simulations of buildings, namely EnergyPlus, eQUEST, and so forth. That helps to calculate the annual energy consumption of buildings with many advanced features. S1 is of the view that *"these software packages generate useful insights and present a comprehensive report at the end of the analysis."* As a result, 'the ability to use LCA software packages' is identified as an extremely important opportunity.

According to S2 and S3, the most distinctive LCA Manual called the ILCD Handbook, which properly guides the LCA practitioners, has recently been released. Hence 'the ability to use standardise LCA guidelines and handbooks' becomes an extremely important opportunity. Considering one of the other opportunity of 'availability of platform' S3 and S4 explained that LCADeSNet was conducted programs on LCA with the participation of representatives in government organisations such as Sustainable Energy Authority, Central Environmental Authority, Sri Lanka Standard Institution, National Research Council, etc. hence the 'availability of platform' could be identified as an extremely important opportunity.

BIM could cause positive impacts on three pillars of sustainability due to its specific characteristics. S3 explained, *"as for the economic aspects, BIM could reduce costs through effective information management, and it could enhance coordination, with the use of fewer resources. Regarding social aspects, BIM facilitates the analysis and simulation of several parameters (e.g., daylight, energy, etc.) to make a better working and living environment by improving comfort and well-being. From an environmental* *point of view, BIM supports to conduct different environmental analyses. Environmental, economic, and social performances could be further improved through the integration of LCA with BIM."* However, the application of BIM is not deeply-rooted in the Sri Lankan construction industry, which makes it a neutral opportunity.

4.11.2 Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Society

The following section presents the developed repertory grid for the weaknesses and threats encountered by society when establishing LCA.

Table 4.11: Repertory Grid for the Weaknesses and Threats in Establishing LCA in the Sri Lankan Construction Industry: Society

Internal Perspective										
I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential					**Negative Factors**	**External Perspective I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Weaknesses					
					I. Unavailability of experienced LCA professionals					
					II. LCA for the buildings are more complex than LCA for conventional products					
					III. Limited awareness of LCA as a decision-making tool to assess environmental performances within the construction industry					
					Threats					
					IV. Unavailability of accurate LCA data					
					V. Absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA					
					VI. Lack of appreciation for the application of LCA					
					VII. Limited availability of platforms to publicise LCA concept					
					Rejected Weaknesses and Threats					
					VIII. The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)					

IX.	Problems in credibility and understanding of LCA results
X.	Lack of favorable governmental incentives
XI.	Non-integration of LCA with building management software (e.g., Building Information Modeling)
	Newly Added Threats
XII.	LCA is associated with excessively complicated calculations
XIII.	Poor cooperation between LCA practitioners and stakeholders in the construction industry

Number of interviewees agreed to the statement out of four	Color Code
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4.11, ‘unavailability of experienced LCA professionals,’ ‘LCA for the buildings are more complex than LCA for conventional products,’ and ‘limited awareness of LCA as a decision-making tool’ identified as weaknesses. Considering the ‘unavailability of experienced LCA professionals,’ S3 stated that *“the few experienced and educated construction professionals in the field of environmental protection, and most professionals do not have the experience or education of LCA, and further some of them are not seeking the continuous professional development required by the industry caused this as an influential weakness.*

Some interviewees disagree that the building’s LCA is more complicated than traditional products, but some agree. S1 and S3 believe that the LCA of a building is more complicated due to the complexity of its life cycle stages. However, on the contrary, S4 held different opinions and stated that *“despite the complexity, LCA could be easily performed using different software packages.”* When considering the "high cost of performing LCA" LCA is costly because of the great need for LCA data and due to the professional fee for experts. In contrast to this, S4 stated that *"due to the funding schemes that support the development of environmental protection activities, this does not have much impact on the contender of society."*

'Unavailability of accurate LCA data', 'absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA', 'lack of appreciation for the application of LCA' and 'limited availability of platforms to publicise LCA concept' identified as threats. S4 highlighted that *"the data collection includes all data related to the inputs and outputs of energy and materials as well as mass flow related to the discharge of water, air, and land. And it is very difficult to collect data due to the unavailability of Sri Lankan databases."* Therefore, 'unavailability of accurate LCA data' could be regarded as a highly influential threat. The results were showed that "the lack of appropriate legislative measures and competent authorities" has a great influence. S3 and S4 explained that the enforcement of LCA-based environmental policies is a function of the government to ensure that the LCA and life cycle thinking are widely accepted in the industry. However, there is a lack of mandatory policies and regulations to encourage stakeholders to adopt LCA, which made this threat highly influential. The threat of 'lack of appreciation for the application of LCA' identified as an extremely influential threat. S2 stated that *"due to the huge impact of the construction industry and government intervention to transform the construction industry into green, stakeholders have gradually applied environmental assessments, such as LCA. To further promote these applications, existing applications of LCA needs to be appreciated."* Further, "limited availability of platforms to publicise LCA concept" is considered to have a great influence. According to S4, *"only a few organisations are available to promote the LCA concept, nevertheless, these organisations, are not functioning well."*

According to S3, *"incentives are essential to encourage the adoption of LCA, and the government has a responsibility to provide incentives to influence people's behavior on the application of LCA."* Lack of favorable governmental incentives" is varied between the neutral and slightly influential threat to the establishment of LCA due to the allocation of funds for environmental protection for the environmental NGOs. Concerning the 'non-integration of LCA with building management software.' S3 stated that *"in developed countries, the trend of integrating LCA and BIM is emerging to enable project participants to capture environmental impacts to support decision-making accurately."* On the contrary, in Sri Lanka, since the LCA is not integrated with BIM and BIM is not essential to perform LCA. Hence the non-integration of LCA and BIM is determined to have a slight and no impact.

Figure 4.4 presents SWOT analysis, which was developed with the use of findings derived from the repertory grids presented in (Table 4.10 and Table 4.11).

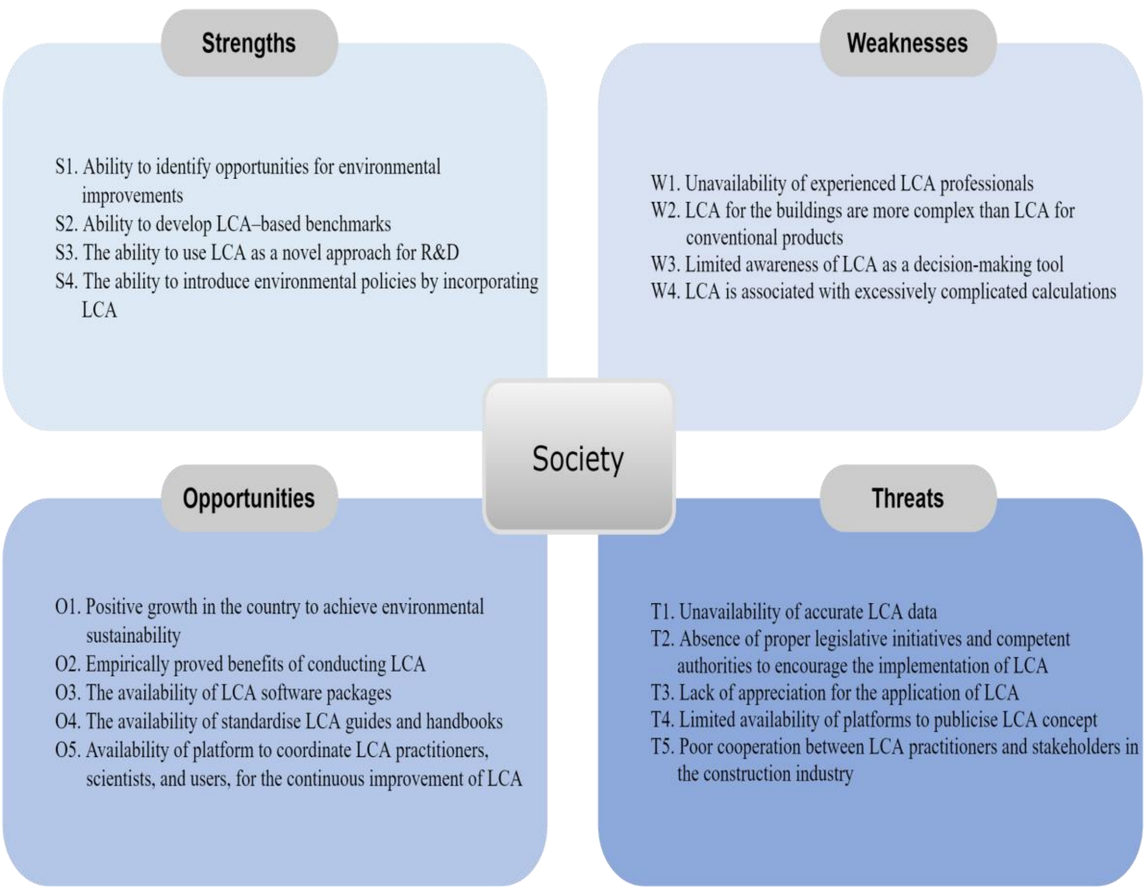

Figure 4.4: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from a Society Perspective

4.11.3 Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Society

The following section presents the identified strategies to overcome weaknesses and threats faced by society in establishing LCA in the construction industry.

Table 4.12: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Society

Respondent ID	Recommended Strategy	Target Weaknesses and Threats
S2 and S3	**SS1. NGOs should increase the level of scrutiny over the construction sector regarding the environmental consequences of their activities** Monitor environmental protection activities conducted by governmental actors accordingly	T2
S2, S3, and S4	**SS2. Encourage academics who have done LCA-related research to publish their research results** Stakeholders in the construction sector could use this information to make investment-oriented and strategy-oriented decisions (e.g. emission reduction strategies) in which LCAs are currently in limited use. And encourage to organise forums based on LCA to address environmental impacts of construction activities such as climate change, waste generation, and the depletion of natural resources	W1, W2, W3, W4, and T1
S1	**SS3. Collaborate with the government to enforce the public policies incorporated by LCA to regulate construction activities** Since the LCA methodology proactively recognises the risks throughout the lifecycle of the building and recommends strategies to deal with these risks. It also helps construction companies to comply with the country's environmental regulations and legislation to meet national standards. Also, this helps stakeholders in the construction sector to carry out construction activities by following environmental regulations to bridge the deviation between theory and practice	W3 and T2, T5
S1	**C4. Use LCA for environmental communication** Consumers are giving attention to environmental aspects when making purchasing decisions. Environmental aspects have never been a concern before to this degree, but the growth of environmental awareness in recent years has increased consumers' consideration of environmental aspects. A reliable method is required to communicate the environmental impacts of products. LCA is a widely accepted method of	T1

	communicating environmental aspects and is a suitable tool to communication for a large audience.	
A1, A4, G2, C3, C4, S1, S3 and E3	**C1. Promote multi-stakeholder and cross-sector collaborations by establishing a network or platform to gather research bodies, government bodies, LCA professionals, environmentalists, and representatives from NGOs** .	T4
A1, A2, G1, C1, C4, S1, S3, E3 and E4	**C2. Actively participate in the development of LCA database**	T1
A2, G3, C2, C3, S1, S3, E1 and E3	**C3. Take actions to make the people aware about the LCA concept**	W1, W2, W3
A1, A2, G2, C1, S3, S4, E3	**C4. Use LCA for environmental communication**	T1
A3 and A1	**SA1. Contribute to the knowledge production and implementation of LCA by expanding and deepening research activities**	W2, W3, and T1
G1, G2, G3, and G4	**SG3. Provide funding for research and development activities on LCA and database development activities**	T1
G3	**SG5. Appraise the application of LCA for the mega-scale construction projects**	T3
G4 and G2	**SG4. Use LCA principles to establish an effective regulatory framework to ensure ecologically sensitive construction practices**	T2

4.12 Contenders in the Quintuple Helix Innovation Model: Environmentalists

The following sections present the evaluation results of the environmentalists' strengths/opportunities and weaknesses/threats in establishing LCA in the Sri Lankan construction industry. Further, the identified positive factors and negative factors were evaluated from an internal perspective against the external perspective with the use of the repertory grid interview technique to identify strengths/opportunities and weaknesses/threats separately. Then, two repertory grids were developed. Moreover, SWOT analysis was developed with the use of findings derived from the repertory grids.

Finally, strategies to overcome weaknesses and threats in establishing LCA in the construction industry were identified.

4.13.1 Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Environmentalists

The following section presents the developed repertory grid for the strengths and opportunities encountered by environmentalists when establishing LCA.

Table 4.13: Repertory Grid for the Strengths and Opportunities in Establishing LCA in the Sri Lankan construction industry: Environmentalists

Internal Perspective						**External Perspective**				
I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important					**Positive Factors**	**I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Strengths					
					I. Ability to identify opportunities for environmental improvements					
					II. Ability to develop LCA–based benchmarks (e.g., energy consumption)					
					III. Use of LCA to develop eco-labeling criteria and EPDs for communication purposes					
					IV. The ability to use LCA as a novel approach for R&D					
					V. The ability to introduce environmental policies by incorporating LCA					
					Opportunities					
					VI. Positive growth in the country to achieve environmental sustainability					
					VII. Empirically proved benefits of conducting LCA					
					VIII. The availability of LCA software packages					
					IX. The availability of standardise LCA guides and handbooks					
					X. Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA					

Rejected Strengths and Opportunities			
XI. Use of Building Information Modeling (BIM) with LCA tools			
XII. Ability to obtain marketing benefits			

Number of interviewees agreed to the statement out of four	Color Code
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4.13, 'the ability to identify opportunities for environmental improvements,' 'ability to develop LCA–based benchmarks', 'use of LCA to develop eco-labeling criteria and EPDs for communication purposes', 'the ability to use LCA as a novel approach for R&D' and 'the ability to introduce environmental policies by incorporating LCA' identified as strengths. 'The ability to identify opportunities for environmental improvements' is an extremely important strength for the environmentalists. According to E1 and E3 environmentalists, have utilised LCA as an effective tool to document the ecological considerations that need to be considered when making decisions towards reducing environmental impacts. For example, E1 insisted that *"LCA could be successfully utilised to analyse different types of waste management options such as landfill, recycling, and energy recovery to determine which type of waste management option is the best for a particular material."*

According to E1, 'ability to develop LCA–based benchmarks' is an important strength for environmentalists as LCA-based benchmarking provides a tool to recognise inefficiencies that need to be improved to achieve better environmental performance. According to E3's point of view, *"this becomes extremely important strength since environmentalists are guiding organisations to improving their environmental performance and demonstrating environmental stewardship using LCA-based benchmarks to increase the organisation's* *reputation and to attract potential environmentally-conscious customers."* One of the other strengths is 'ability to use LCA to develop eco-labeling criteria and EPDs for communication purposes, which is varied between an extremely important and neutral. According to E2, *"the EPD that based on ISO 14025 describes the life cycle environmental performance of products to guide designers in making the best environmental choices when choosing materials and components. Therefore, currently, environmentalists are used LCA–based information to develop eco-labels. However, developing EPDs are not well established in Sri Lanka yet."*

"The ability to use LCA as a novel method for R&D" is an extremely important strength. E4 stated that *"as people are increasingly interested in green buildings, the construction industry has become interested in purchasing green materials and ensuring green supply chains in the construction industry. Existing tools and methods are not sufficient to visualise the environmental impact of life cycle stages. Therefore, environmentalists are actively involved in the development of country-specified novel tools to visualise the environmental impacts of building materials and products with the use of LCA"*. One of the other strengths is 'the ability to introduce environmental policies by incorporating LCA' which has become an extremely important strength to establish LCA in the construction industry. E4 emphasised that *"different types of organisations (e.g., building material suppliers, contractor organisations, etc.) in the construction industry should set goals to reduce impact. Environmentalists have been guided these organisations to use LCA based information to formulate internal environmental policies to achieve specific goals on time, and then the results could be communicated to internal and external stakeholders effectively."*

'Positive growth in the country to achieve environmental sustainability', 'empirically proved benefits of conducting LCA', 'the availability of LCA software packages', 'the availability of standardise LCA guides and handbooks' and 'availability of the platform to coordinate LCA practitioners, scientists, and users' identified as opportunities. Considering the 'positive growth in the construction industry to achieve environmental sustainability' identified as an extremely important opportunity. As per the opinion of E4, *"the impact on the environment result in financial costs, whether it be higher costs for electricity or water and further increased business risks due to violation of environmental standards. Hence, there is a growing tendency to use LCA to achieve sustainability while reducing costs"*. One of the other opportunities of 'the ability to use LCA software packages' categorised as an extremely important opportunity. E2 and E4 disclosed that there are several building-oriented LCA software packages developed in various parts of the world, for instance, EcoQuantum in the Netherlands, Envest in the UK, and ATHENA in North America. The complex calculations involved in LCA could be easily performed using LCA software packages. 'The ability to use standardise LCA guidelines and handbooks could be recognised as an extremely important opportunity. For example, according to E2, *"standardise LCA guides and manuals, could also be used as a guide for first-time users of LCA and make a valuable reference to experienced practitioners in the successful implementation of LCA."*

E3 emphasises that *"LCA is being bloomed in Sri Lanka, and the first conference on LCA was successfully carried out by NCPC Sri Lanka with the participation of academics, industrialists, environmental professionals, and government institutes. The current state of the LCA applications in Sri Lanka was exposed at the conference by highlighting the LCA applications in different scenarios in Sri Lanka. The purpose of this conference was to motivate the Sri Lankan stakeholders to establish LCA-based activities within their organisations."* Accordingly, it could be identified that the 'availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA' as an extremely important opportunity.

According to E1, E2, E3, and E4, in Sri Lanka, LCA is not used to obtain marketing benefits, which make 'ability to obtain marketing benefits' neutral and less important opportunity. In recent years, the use of BIM has supported complex decision making by connecting and integrating several aspects in developed countries. Consequently, E2 mentioned that *"construction-related disciplines are moving to BIM applications. LCA* *would also need information integrated with BIM to make sustainable decisions in the future, but at present, it could not be defined as an opportunity for Sri Lanka, therefore "using BIM with LCA tools" is considered a less important opportunity."*

4.13.2 Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Environmentalists

The following section presents the developed repertory grid for the weaknesses and threats encountered by environmentalists when establishing LCA.

Table 4.14: Repertory grid for the weaknesses and threats in establishing LCA in the Sri Lankan Construction Industry: Environmentalists

Internal Perspective						**External Perspective**				
I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential					**Negative Factors**	**I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential**				
I	**II**	**III**	**IV**	**V**		**V**	**IV**	**III**	**II**	**I**
					Weaknesses					
					I. LCA for the buildings are more complex than LCA for conventional products					
					II. The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)					
					Threats					
					III. Unavailability of accurate LCA data					
					IV. Absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA					
					V. Lack of favorable governmental incentives					
					VI. Lack of appreciation for the application of LCA					
					VII. Limited availability of platforms to publicise LCA concept					
					Rejected Weaknesses and Threats					
					VIII. Unavailability of experienced LCA professionals					

	IX. Limited awareness of LCA as a decision-making tool to assess environmental performances within the construction industry	
	X. Non-integration of LCA with building management software (e.g., Building Information Modeling)	
	XI. Problems in credibility and understanding of LCA results	
	Newly Added Threats	
	XII. The priority is given to economic factors rather than environmental factors	
	XIII. Reluctance to shift from the conventional methods	

Number of interviewees agreed to the statement out of four	Color Code
One out of four (1/4)	
Two out of four (2/4)	
Three out of four (3/4)	
Four out of four (All)	

According to Table 4.14, 'LCA for the buildings are more complex than LCA for conventional products,' and 'the high cost of performing LCA,' recognised weaknesses. Considering the LCA for the buildings are more complex than LCA for conventional products' building construction projects are now more complex, many of which have sophisticated systems, use different building materials. E3 highlighted that compared to traditional products, buildings are much more complex to assess, and this is categorised between influential and an extremely influential weakness to the environmentalists. E2, E3, and E4 elaborated that Sri Lanka is still trying to implement LCA, so the widespread adoption of LCA has been greatly impacted by the lack of experienced professionals in other contenders. On the contrary, the availability of LCA professionals in this area has little impact on environmentalists, as most of the environmentalists are aware of LCA. Accordingly, the 'unavailability of experienced LCA professionals' and 'limited awareness of LCA as a decision-making tool' poses slightly influential weaknesses to the environmentalists. When considering the 'problems in credibility and understanding of

LCA results' E1 and E4 stated that due to the thorough understanding of LCA results by environmentalists, problems in understanding the results of LCA had become a neutral and slightly influential weakness for them.

'Unavailability of accurate LCA data', 'absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA', 'lack of favorable governmental incentives', 'lack of appreciation for the application of LCA' and 'limited availability of platforms to publicise LCA concept' identified as threats for the environmentalists in establishing LCA. 'Absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA' is considered an influential threat. As, E1 stated that *"LCA is not deeply integrated with policy levels and a very limited number of organisations are taking initiatives to implement LCA within Sri Lanka, which is inadequate."* 'Lack of favorable governmental incentives' is considered an extremely influential and influential threat. As E1 highlighted that *"incentives serve as persuaders that influence the construction industry to adopt LCA and incorporate life cycle thinking practices into their construction projects, and lack of favorable governmental incentives identified as an extremely influential threat."* One of the other threats is 'lack of appreciation for the application of LCA' as applications of LCA into the Sri Lankan construction sector are unlikely to be appreciated, and this became one of the most influential threats. Therefore, E4 noted that *"it is better to value and appreciate the work done by LCA practitioners to reduce environmental impact."*

E2 and E4 mentioned that LCADeSNet, as one of the organisations promoting LCA, and it arranged the capacity building program in collaboration with the Ministry of Mahaweli Development and Environment and UNEP. The goal of the seminar is to promote the concept of LCA as a decision-making tool by highlighting the empirically proven benefits of using LCA. However, according to E3, *"it could be identified a very limited number of organisations that conduct LCA promotional activities that are not sufficient to promote LCA within the Sri Lanka construction industry"* And the "limited availability of platforms to publicise LCA concept" poses a serious threat. 'The priority is given to economic factors rather than environmental factors' and 'reluctance to shift from the conventional methods' identified as a threat to the environmentalists.

Figure 4.5 presents SWOT analysis, which was developed with the use of findings derived from the repertory grids presented in (Table 4.13 and Table 4.14).

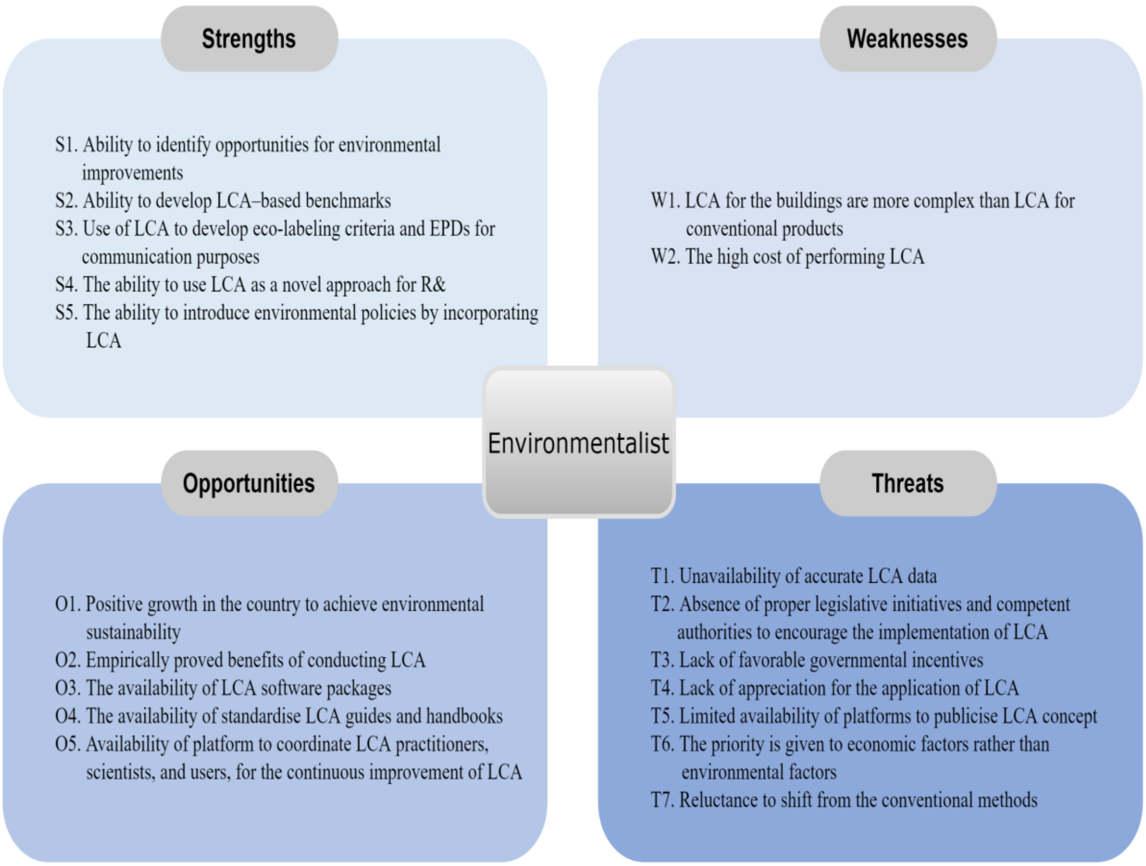

Figure 4.5: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Environmentalists Perspective

4.13.3 Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Environmentalists

Although the weaknesses and threats that emerged during the application of LCA for the construction industry in Sri Lanka could be overcome by applying certain strategies. Hence, it was required to determine the strategies to enhance the application of LCA.

Table 4.15 is presented the appropriate strategies recommended by the interviewees to enhance the LCA application in Sri Lanka.

Table 4.15: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Environmentalist

Respondent ID	Recommended Strategy	Target Weaknesses and Threats
E4	**SE1. Encourage academic people to conduct LCA-related research activities and publish their research findings** Since the LCA helps to make accurate decisions by choosing the best available technologies and building materials to reduce the environmental impact of construction.	W1
E2	**SE2. Assist in developing a vigorous environmental policy framework and renewed it periodically** An environmentalist could contribute their knowledge to develop LCA incorporated public policies to regulate construction activities. Governments could use environmentalists' assistance to develop relevant policies focusing on sustainable consumption and production, waste management, emission reduction, energy management, etc.	T2
E1, E2, E3, and E4	**SE3. Educate the whole society about sustainable initiatives and the potential financial benefits of using LCA (e.g reducing the cost incurred by minimising material waste, minimising energy use, etc.** Stakeholders' consciousness towards LCA could be improved by increasing their knowledge and understanding. The LCA helps to identify profit opportunities throughout the entire life cycle, to achieve significant advantages over its competitors.	T6, T7
E3	**SE4. Promote Eco-innovation concept with the use of the LCA approach and to use LCA data for communication** Eco-innovation could be identified as any type of innovation targeting at significant progress to achieve environmentally friendly development, through decreasing impacts on the environment or obtaining benefits from the efficient use of energy and natural resources. Moreover, Eco-innovation converts the LCA approach to practice by giving solutions for the environmental problems associated with construction activities. Then benefits achieved with the use of eco-innovations can be commutated with internal and external stakeholders.	T6, T7

A1, A4, G2, C3, C4, S1, S3 and E3	**C1. Promote multi-stakeholder and cross-sector collaborations by establishing a network or platform to gather research bodies, government bodies, LCA professionals, environmentalists, and representatives from NGOs**	W1, T1, and T5
A1, A2, G1, C1, C4, S1, S3, E3 and E4	**C2. Actively participate in the development of LCA database**	W1 and T1
A2, G3, C2, C3, S1, S3, E1 and E3	**C3. Take actions to make the people aware about the LCA concept**	W1
A1, A2, G2, C1, S3, S4, E3	**C4. Use LCA for environmental communication**	T1
A3 and A1	**SA1. Contribute to the knowledge production and implementation of LCA by expanding and deepening research activities**	W1, T1
G1, G2, G3, and G4	**SG3. Provide funding for research and development activities on LCA and database development activities**	T1
G3	**SG5. Appraise the application of LCA for the mega-scale construction projects**	T4
G2	**SG1. Government intervention by providing financial incentives**	T3, W2
G4 and G2	**SG4. Use LCA principles to establish an effective regulatory framework to ensure ecologically sensitive construction practices**	T2

4.14 A modified Quintuple Helix Innovation Model integrating the Significant Contender Roles and Strategies for LCA Integration to the Construction Industry

The modified Quintuple Helix Innovation Model presents in Figure 4.6 (Figure 4.6 displays the initial layout of the model, Figure 4.7, 4.8, 4.9, 4.10, and 4.11 present SWOT analysis of Academia, Government, Construction Industry, Society, and Environmentalists respectively. And finally, Figure 4.12 presents the strategies for establishing LCA in the construction industry.) contains five (05) contenders; academia, government, construction industry, society, and environmentalists with their own strengths/opportunities and weaknesses/threats. Each contender's strengths and opportunities provide a resourceful background to enhance the ability of LCA applications within the construction industry and each contender's weaknesses and threats also hinder the establishment of LCA in the construction industry. Therefore these weaknesses and threats must be minimised or eliminated to assist the establishment of LCA in the construction industry. Then, strategies are identified to overcome these weaknesses and threats faced by each contender in establishing LCA for the Sri Lankan construction industry. Even if each contender determines strategies, the weaknesses and threats cannot be completely minimized or eliminated by themselves. Therefore, each contender needs to cooperate with each other to promote the successful establishment of LCA in the Sri Lankan construction industry while minimizing and eliminating weaknesses and threats.

For instance, one of the threats faced by the contender of the construction industry is the "unavailability of accurate LCA data" which cannot be eliminated or minimised by the use of strategies recommended by the construction industry itself. Hence, the strategies recommended by academia and government also have to be utilized cooperatively to eliminate or minimise that threat. According to the above-mentioned threat, strategies such as SC5, SA1, and SG3 have to be used to eliminate or minimise that threat. Accordingly, respective strategies are identified for all weaknesses and threats faced by contenders in establishing LCA. (SA: Strategy Academia, SG: Strategy Government, SC: Strategy Construction industry, SS: Strategy Society, SE: Strategy Environmentalists, and SC: Common strategies recommended by all contenders).

Moreover, each contender takes input from the knowledge circulation process and creates new knowledge or innovations and consequently, newly created knowledge or innovations acts as out to the knowledge circulation process. It could be identified that knowledge creation is the outcome of the input, on the other hand, the output of knowledge creation is the production of innovations or newly created knowledge. As an example, the purpose of using LCA by environmentalists is to “protect the environment” which could be identified as the input to the contender of environmentalists. Then, within this contender, protecting the environment could be achieved by eliminating the weaknesses and threats with the help of strategies. After achieving the desired objective, the result is considered as the output to the knowledge creation which identified as Sustainable know-how and raising environmental awareness. In the knowledge circulation process, the flow of knowledge continually stimulates and generates new knowledge and innovations by giving inputs to the contenders and taking outputs from the contenders. Likewise, all contenders in the Model of Quintuple Helix influence one another through circulating knowledge among themselves to promote innovations so, it could be noted that all contenders in the Modified Quintuple Helix Innovation model are interacting with each other through knowledge circulation. Finally, this model could be effectively used to identify contender roles in establishing LCA for the construction industry.

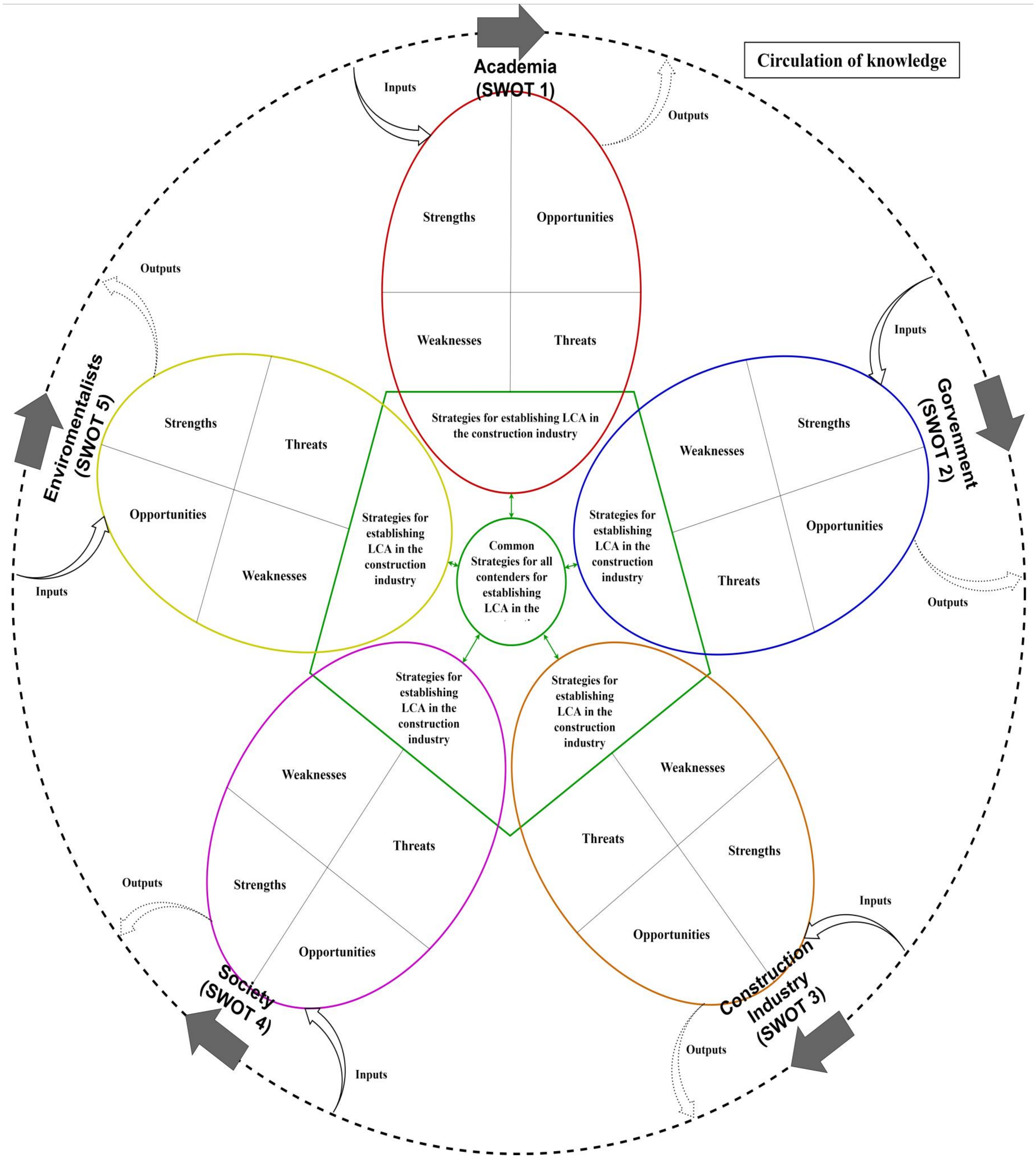

Figure 4.6: Initial Layout of the Modified Quintuple Helix Innovation Model integrating the Significant Contender Roles and Strategies for LCA Integration to the Construction

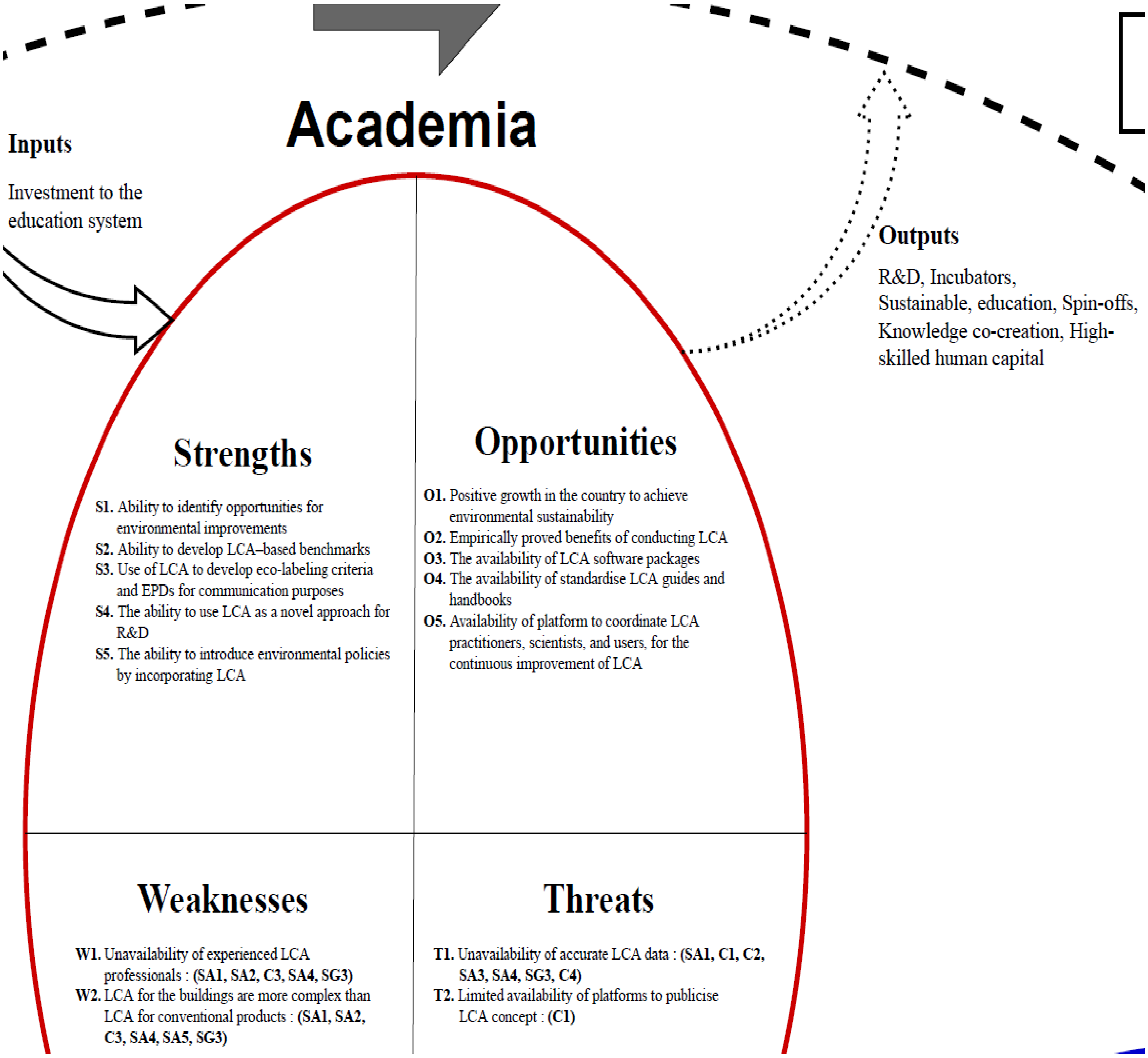

Figure 4.7: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Academic Perspective

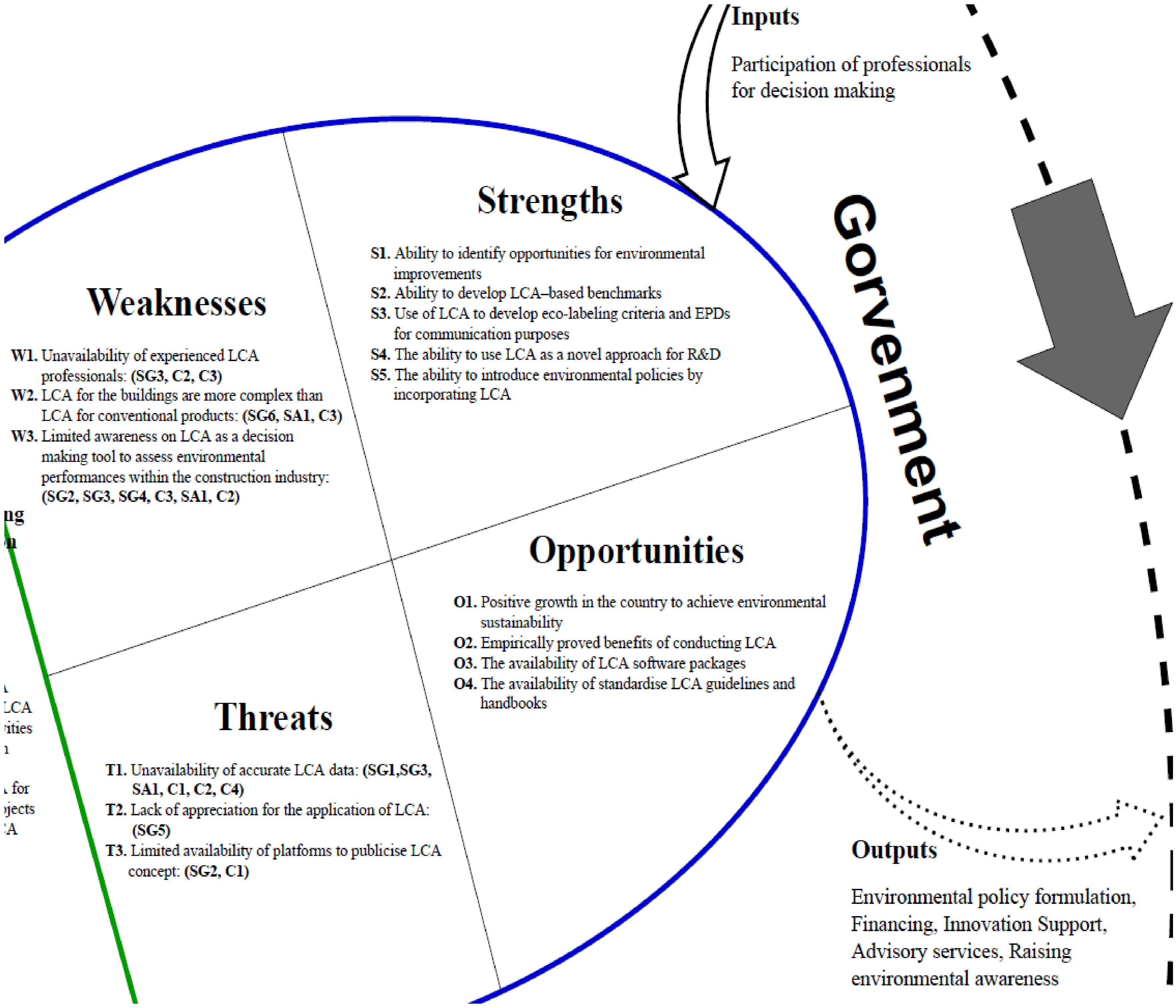

Figure 4.8: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from the Government Perspective

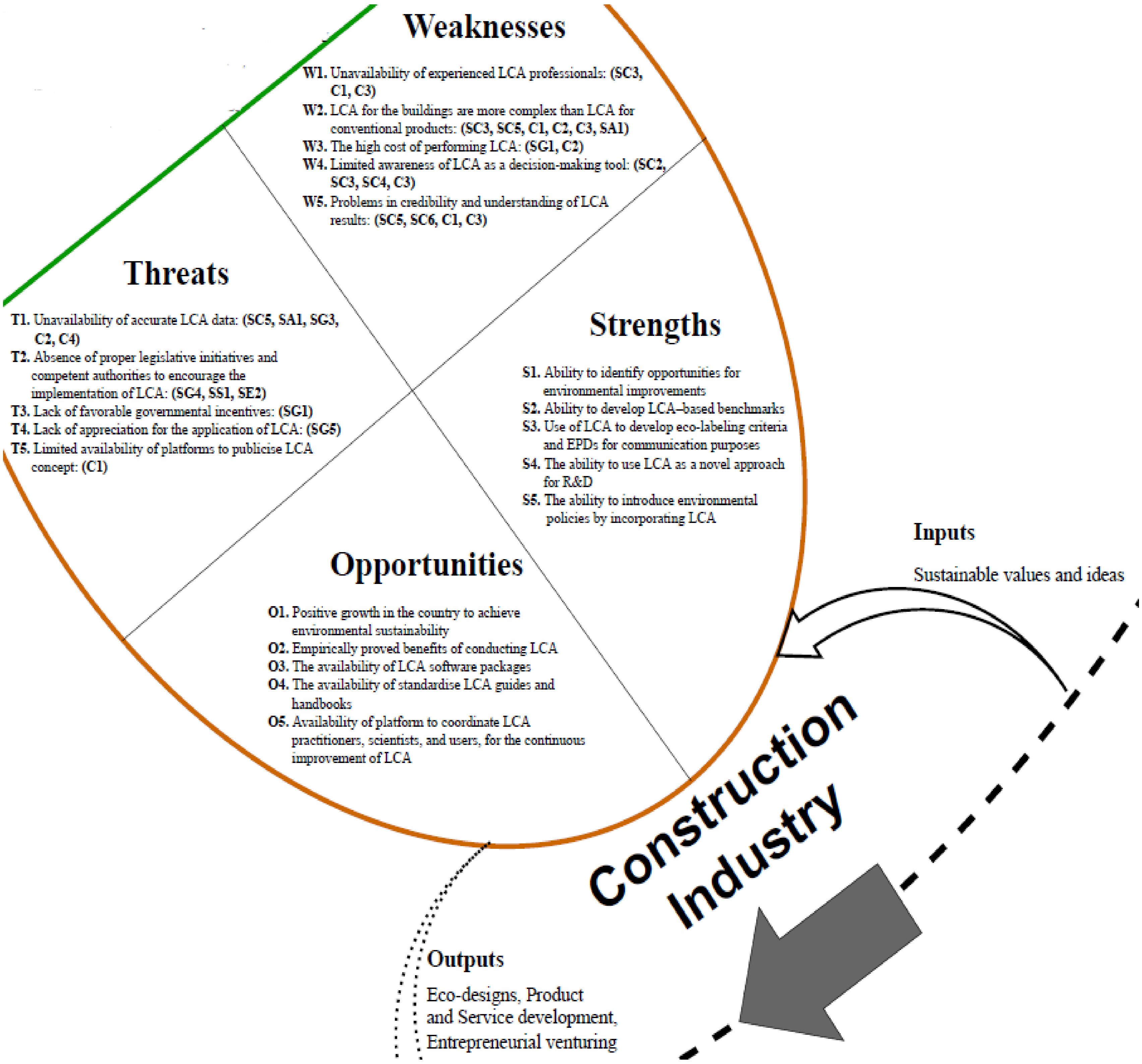

Figure 4.9: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry

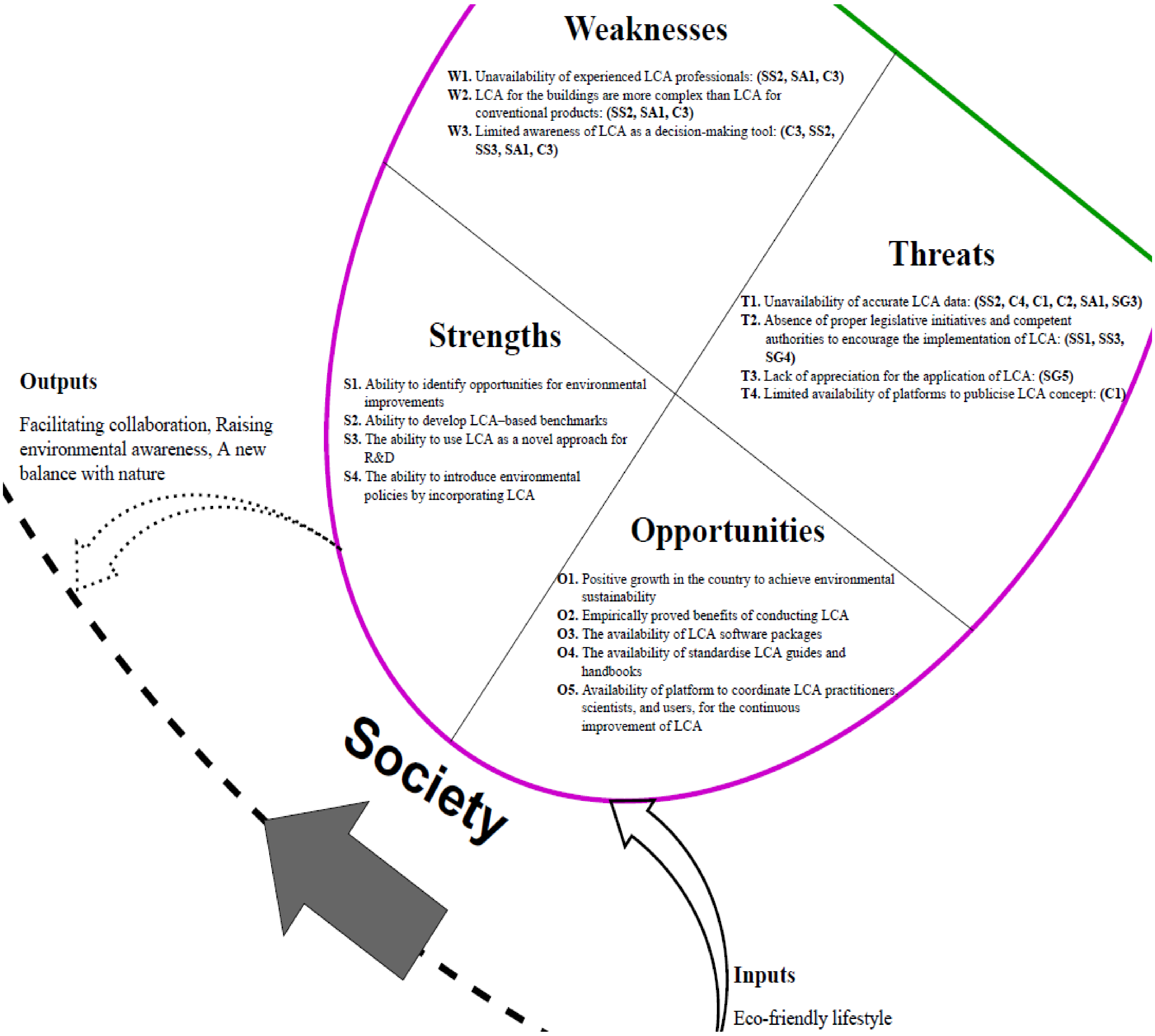

Figure 4.10: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from a Society Perspective

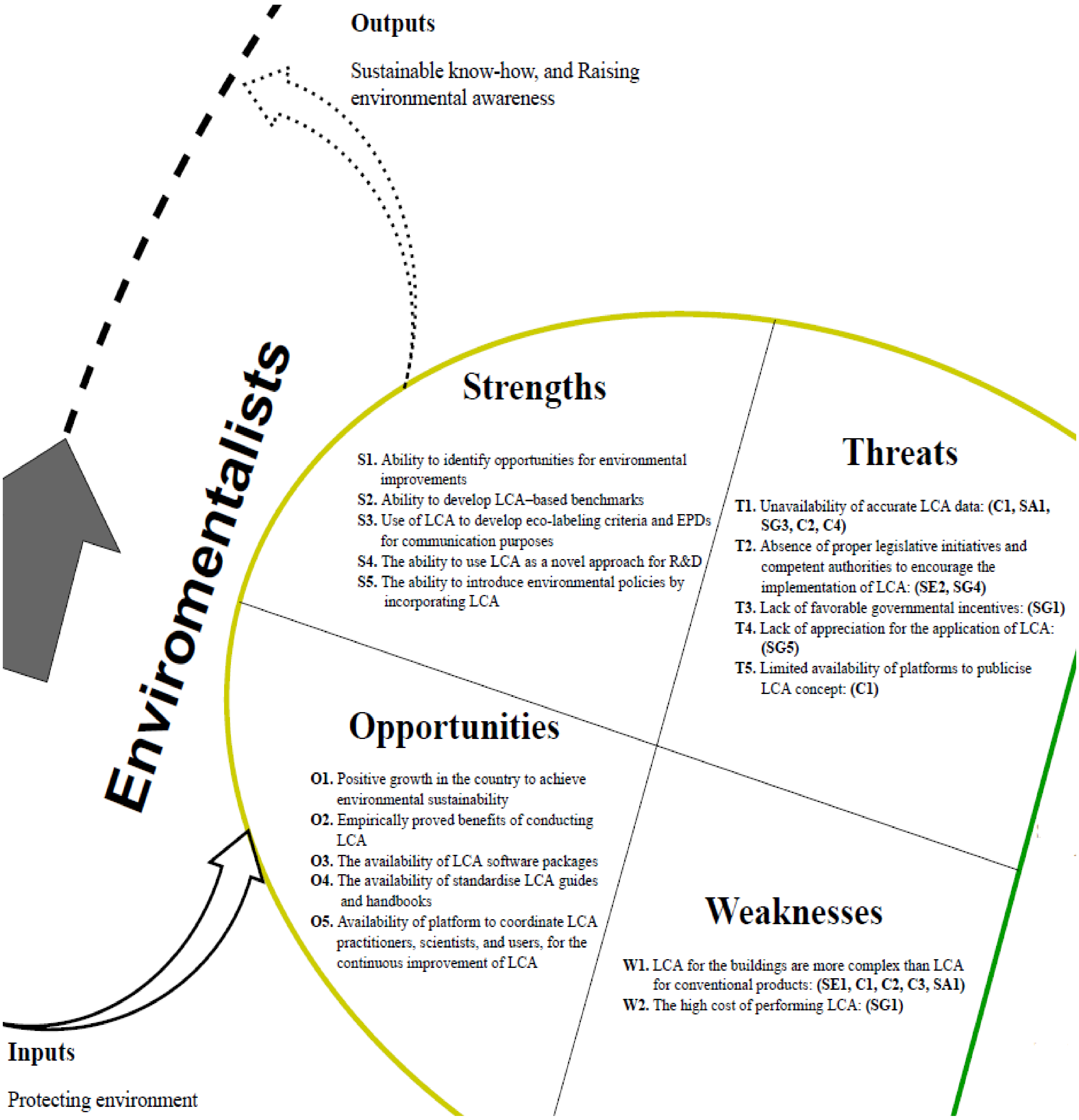

Figure 4.11: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Environmentalists Perspective

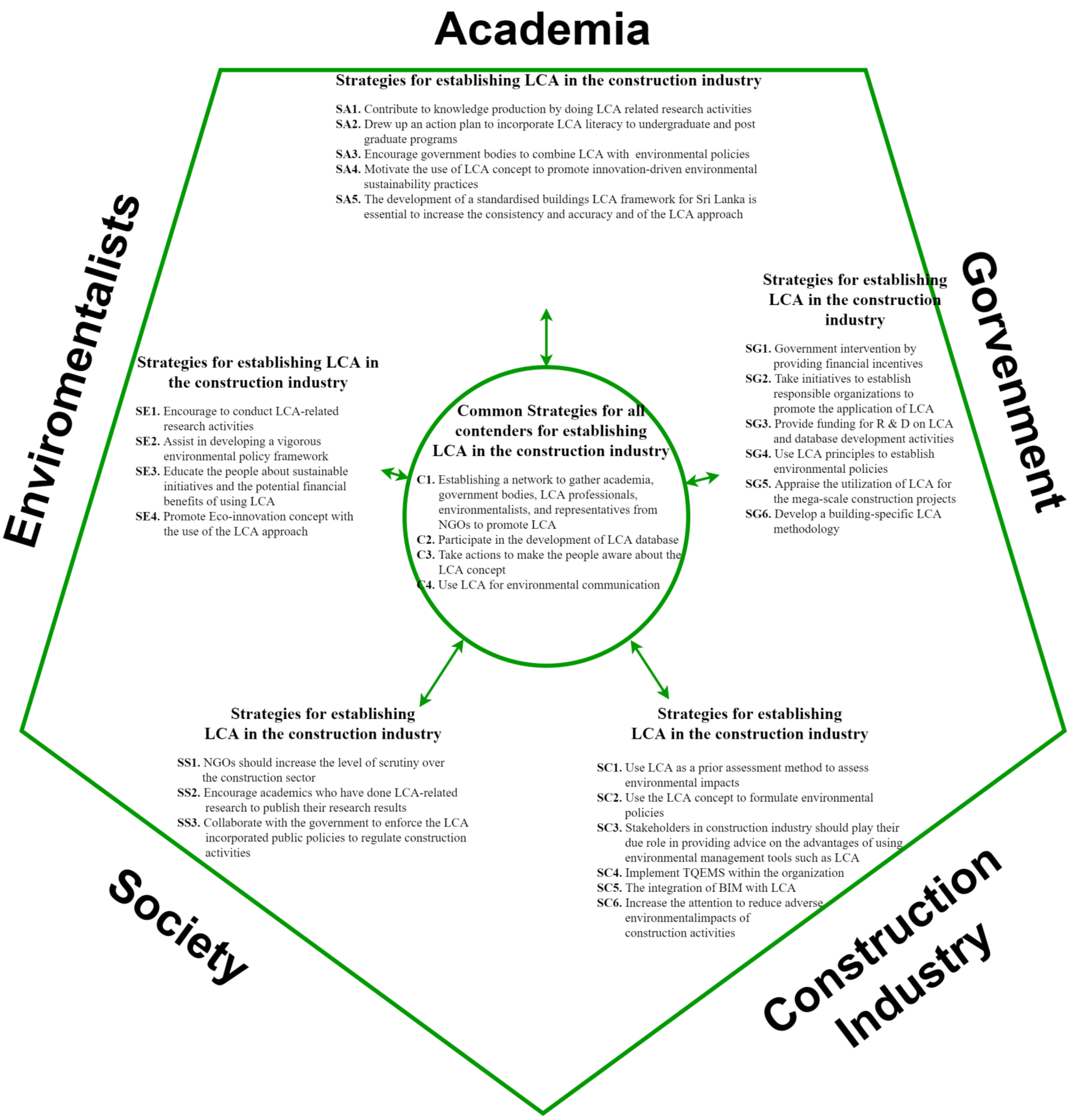

Figure 4.12: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry

4. 15 Summary

This chapter initially focused on identifying the importance of establishing LCA for the Sri Lankan construction industry. Then recognised strengths and opportunities from the literature synthesis were presented to interviewees from each contender for evaluating their relative importance from an internal perspective versus an external perspective. Similarly, weaknesses and threats identified from the literature synthesis were presented to respondents from each contender to evaluate their level of influence from an internal perspective versus an external perspective. Evaluating the strengths/opportunities and weaknesses/threats for establishing LCA in the construction industry in internal vs. external perspectives. Then, two repertory grids were developed for each contender. Then, SWOT analysis was developed with the use of findings derived from the repertory grids. Consequently, strategies to overcome weaknesses and threats in establishing LCA in the construction industry were identified. Finally, a modified Quintuple Helix Innovation Model was developed by integrating the significant contender roles and strategies for establishing LCA in the construction industry.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter discusses the overview and conclusions of the research findings, which will add value to existing knowledge in this field of study and contribute to future research studies. Also, it reveals the limitations of the study. Finally, recommendations are made to academic researchers and industry practitioners to establish LCA within the Sri Lankan construction industry effectively.

5.2 Conclusions Drawn from the Study

The conclusions drawn from this research on each of the respective predefined objectives are discussed as follows;

Objective 1:- Critically review the factors influencing on LCA application in the construction industry with reference to the essential stakeholders

The study revealed that developing countries pay less attention to implementing LCA in the construction industry compared to developed counties. Also, the construction industry in developing countries has been in the position of highly vulnerable to face environmental degradation as a result of the booming nature of constructions, which drastically increases multi-facetted environmental challenges. In considering Sri Lanka as a developing county, many views emphasise the implementation and adaptation of LCA limited in the construction industry. However, it has become a key requirement for establishing LCA in the Sri Lankan construction industry as a solution to reduce the increasing adverse environmental impact

The identified contradictions between developed and developing countries emphasise the need to investigate as to why developing countries do not implement LCA. Therefore, this objective explores the positive factors faced by developed countries, as well as the negative factors faced by developing countries in establishing LCA in the construction industry. Literature findings emphasised the twelve (12) number of positive factors (refer Table 2.1) enjoyed by developed countries (e.g., organisation of workshops and forums on LCA, the availability of region-specific LCA software packages to perform the LCA easily, etc.) which have improved the capacity of LCA applications. Therefore, developing countries also should strive to integrate the identified positive factors into their construction industries to facilitate a resourceful background to establish LCA. Further, literature findings indicate the eleven (11) number of negative factors (refer Table 2.2) faced by developing countries in establishing LCA (e.g., unavailability of experienced LCA professionals, limited awareness about LCA as a decision-making tool, etc.). Therefore, developing countries should do their utmost to minimise the negative factors encountered when establishing LCA in their construction industries.

The positive factors enjoyed by developed countries highlighted that LCA had been successfully implemented in the construction industry in developed countries due to the cooperative activities between the essential stakeholders such as academia, environmentalists, environmental managers, investors, architects, government, regulatory agencies, the general public, policymakers, designers, contractors, NGOs, and engineers. Furthermore, findings reveal that lack of contribution and coordination amongst the stakeholders mentioned above poses challenges to implement LCA into the construction industry in developing countries.

Objective 2:- Propose the essential contextual stakeholders for establishing LCA in the construction industry aligned with the Quintuple Helix Innovation Model significant contenders

The establishment of LCA to the construction industry could be seen as a collaborative activity that would have an impact on the above-identified essential stakeholders (in objective 2). As such, it could be highlighted that the establishment of LCA with the construction industry is an innovation that sustains the agglomerations of the aforementioned essential stakeholders. It could be determined that the appropriate model for analysing this complex and collaborative innovation introduced by the LCA into the construction industry is the "Quintuple Helix Innovation Model" because it produces a synergy between academia, government, construction industry, society, and environmentalists.

Then, essential stakeholders for establishing LCA in the construction industry derived from the positive factors aligned with the Quintuple Helix Innovation Model significant five (05) contenders such as (01) academia (including academics and researchers), (02) government (including regulatory agencies, policymakers), (03) construction industry (including investors, architects, designers, contractors, and engineers), (04) society (including NGOs and non-profit organisations) and (05) environmentalists (including environmental managers, sustainability consultants, environmental engineers).

Objective 3:- Evaluate the strengths/opportunities and weaknesses/threats for establishing LCA in the construction industry in internal vs. external perspectives

Concerning the academic point of view, ‘ability to identify opportunities for environmental improvements,’, ‘ability to develop LCA–based benchmarks’, ‘use of LCA to develop eco-labeling criteria and EPDs for communication purposes’, ‘the ability to use LCA as a novel approach for R&D’ and ‘the ability to introduce environmental policies by incorporating LCA’ were classified as strengths. Moreover, ‘positive growth in the country to achieve environmental sustainability’, ‘empirically proved benefits of conducting LCA’, ‘the availability of LCA software packages’, ‘the availability of LCA standardise LCA guides and handbooks’ and ‘availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA’ have been identified as opportunities for academia in establishing LCA in the construction industry (refer Table 4.1). Similarly, weaknesses and threats (refer Table 4.2) faced by academia were identified.

Concerning the government perspective, ‘ability to identify opportunities for environmental improvements’, ‘ability to develop LCA–based benchmarks’ and ‘the ability to introduce environmental policies by incorporating LCA’ were identified as extremely important strengths. Further, ‘positive growth in the country to achieve environmental sustainability’, ‘ empirically proved benefits of conducting LCA’, ‘the availability of LCA software packages’, ‘the availability of standardise LCA guidelines and handbooks’ were identified as extremely important opportunities (refer Table 4.4). Also, the ‘unavailability of accurate LCA data’’ and ‘limited availability of platforms to publicise LCA concept’ have been identified as an extremely influential threat for the establishment of LCA for the Sri Lankan construction industry (refer Table 4.5).

Considering the construction industry, several opportunities could be identified such as ‘positive growth in the country to achieve environmental sustainability’, ‘empirically proved benefits of conducting LCA’, ‘the availability of LCA software packages’, the availability of standardise LCA guides and handbooks, and ‘availability of the platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA (refer Table 4.7). Moreover, several weaknesses and threats (refer Table 4.8) faced by the construction industry were identified.

To the society’s point of view, several strengths and opportunities (refer Table 4.10) faced by the society were identified. Moreover, ‘unavailability of experienced LCA professionals,’ ‘LCA for the buildings are more complex than LCA for conventional products,’ and ‘limited awareness of LCA as a decision-making tool’ were identified as weaknesses. Also, ‘unavailability of accurate LCA data’, ‘absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA’, ‘lack of appreciation for the application of LCA’ and ‘limited availability of platforms to publicise LCA concept’ have been identified as threats (refer Table 4.11).

Regarding the environmentalist point of view, several strengths and opportunities (refer Table 4.13) faced by the environmentalist were identified. Moreover, only two weaknesses could be identified, such as ‘LCA for the buildings are more complex than LCA for conventional products,’ and ‘the high cost of performing LCA’. Nevertheless, several threats could be identified as ‘unavailability of accurate LCA data’, ‘absence of proper legislative initiatives and competent authorities to encourage the implementation of LCA’, ‘lack of favorable governmental incentives’, ‘lack of appreciation for the application of LCA’ and ‘limited availability of platforms to publicise LCA concept (refer Table 4.14).

Then, Individual SWOT analysis was developed for five (05) contenders; (01) Academia (refer Figure 4.1), (02) Government (refer Figure 4.2), (03) Construction Industry (refer Figure 4.3), (04) Society (refer Figure 4.4) and (05) Environmentalists (refer Figure 4.5) by identifying their respective strengths/opportunities and weaknesses/threats.

Objective 4:- Develop a modified Quintuple Helix Innovation Model integrating the significant contender roles and strategies for establishing LCA in the construction industry

Finally, a Modified Quintuple Helix Innovation Model was developed (refer Figure 4.6) and it could be employed to motivate all the related contenders to apply LCA as a decision-making tool to assess and mitigate environmental impacts generated by the construction industry.

5.3 Contribution to the Knowledge

This study makes some significant contributions to the prevailing body of knowledge as follows;

- Determining the strengths/opportunities and weaknesses/threats faced five (05) contenders; (01) academia, (02) government, (03) construction industry, (04) society, and the (05) environmentalists in establishing LCA in the Sri Lankan construction industry
- Evaluating strengths/opportunities and weaknesses/threats faced by five (05) contenders in the Quintuple Helix Innovation Model in internal perspectives versus external perspectives
- Proposing strategies to overcome weaknesses and threats faced by five (05) contenders in the Quintuple Helix Innovation Model for establishing LCA in the Sri Lankan construction industry
- Developing modified Quintuple Helix Innovation Model to motivate all the related contenders to apply LCA as a decision-making tool to identify opportunities for environmental improvements in which LCAs are currently used to a limited extent

5.4 Limitations of the Study

In several other industries where LCA applications exist, the current research is based on the construction industry. The booming nature of the construction industry in Sri

Lanka has greatly increased the environmental challenge, which could be resolved and mitigated by establishing LCA in the construction industry to make environmentally sound decisions, in a timely manner. LCA was introduced in Sri Lanka at the end of the 2000s, although it has been used recently and very limitedly in the construction industry in Sri Lanka. Therefore, it is difficult to find experienced professionals in the research field. Consequently, data collection was limited to twenty (20) expert interviews representing academics, government organisations, construction companies, society (NGOs and non-profit organizations), and environmentalists.

5.5 Recommendations for Industry Practitioners

The following are the recommendations made by this study to industry practitioners

1. Encouraging academia, government organizations, construction industry professionals, society, and environmentalists to use the modified Quintuple Helix Innovation Model for understanding their weaknesses and threats in establishing LCA in the Sri Lankan construction industry and preparing for them

2. Using identified strategies to establish LCA in the Sri Lankan construction industry

3. Employing a Modified Quintuple Helix Innovation Model to motivate all the related contenders to apply LCA as a decision-making tool, to identify opportunities for environmental improvements

5.6 Recommendations for Academic Research

This study made further research directions for academics as follow;

1. Develop discrete Quintuple Helix Innovation Models for three stages (e.g., Knowledge Space, Innovation Space, and Consensus Space) in the innovation process to implement LCA to the Sri Lankan construction industry

2. Identification of relationships between five (05) contenders the Quintuple Helix Innovation Model for establishing LCA in the Sri Lankan construction industry

5.7 Summary

There are numerous studies on the implementation of LCA in the construction industry in developed countries. Although, there are fewer studies on the implementation of LCA to the Sri Lankan construction industry. Therefore, the current study developed the Quintuple Helix Innovation Model for establishing LCA in the Sri Lankan construction industry.

Annexure

INTERVIEW GUIDELINE

SECTION I– BACKGROUND INFORMATION ABOUT THE INTERVIEWEE

2. Name of the respondent (optional): ……………………………………………………………….
3. Name of the Organization (optional): ……………………………………………………………..
4. Designation of the respondent: ………………………………………………………………………
5. Work experience (No. of years)…………………………………………………………………...
6. Experience in the field of LCA (No. of years): ……………………………………………………...

SECTION II– STAKAHOLDER CONTRIBUTION TOWARDS LCA IMPLEMENTATION

7. Briefly explain the alarming environmental impacts generated by the construction industry? ....
8. Explain briefly about the general awareness of managing these environmental impacts in Sri Lankan construction industry? ....
9. Do you suggest LCA as a specific decision-making tool to reduce environmental impacts generated by the construction industry? ………..
10. What is the importance of LCA implementation for the construction industry in Sri Lanka? ……
11. What is your contribution to the process of LCA implementation in the construction industry? …….
12. Briefly explain the essential stakeholder contribution in the process of LCA implementation in the construction industry?

A. Academia
………………………………………………………………………………
……….........

B. Construction Industry
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…………......

C. Government
………………………………………………………………………………
…………….

D. Society
………………………………………………………………………………
…………......

E. Environmentalist
………………………………………………………………………………
…………......

SECTION III- REVIEW OF THE LITERATURE FINDINGS

13. As per the literature findings, positive factors and negative factors in implementing LCA for the construction industry can be tabulated as follow. Evaluate and give your opinion on the identified factors in implementing LCA with respect to the Sri Lankan construction industry in internal perspectives against an external perspective based on your knowledge and experience.

Internal Perspective					**Positive Factors**	**External Perspective**				
I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important						**I=Not Important II=Less Important III= Neutral IV = Important V=Extremely Important**				
1	2	3	4	5		5	4	3	2	1
					I. Ability to identify opportunities for environmental improvements with the use of LCA					
					II. Ability to develop benchmarks for different building types with the use of LCA					
					III. To develop eco-labeling criteria and EPDs for communication purposes					
					IV. Positive growth in the country to achieve environmental sustainability					
					V. The ability to use LCA as a novel approach for Research and Development (R&D)					
					VI. Initiation of environmental policies which incorporate LCA					

					VII. Ability to obtain marketing benefits					
					VIII. Empirically proved benefits of conducting LCA					
					IX. The availability of LCA software packages to easily perform the LCA					
					X. The availability of standardise LCA guides and handbooks					
					XI. Availability of platform to coordinate LCA practitioners, scientists, and users, for the continuous improvement of LCA					
					XII. Use of Building Information Modeling (BIM) with LCA tools					
					Any other positive factor observed other than above findings					

Internal Perspective					**Negative Factors**	**External Perspective**				
I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential						**I=Not Influential II=Slightly Influential III = Neutral IV= Influential V=Extremely Influential**				
1	2	3	4	5		5	4	3	2	1
					I. Unavailability of experienced LCA professionals					
					II. Prejudice on LCA for the buildings are more complex than LCA for conventional products					
					III. The high cost of performing LCA (cost of purchasing data from commercial databases, the cost for the primary data collection and LCA professional fees)					
					IV. Unavailability of accurate LCA data with respect to the construction sector					
					V. Limited awareness about LCA as a decision-making tool to assess building environmental performances					
					VI. Absence of proper legislative initiatives and competent authorities to encourage the application of LCA					
					VII. Lack of favorable governmental incentives					

					VIII. Non-integration of LCA with building management software packages					
					IX. Problems in understanding LCA results					
					X. Lack of appreciation for the application of LCA					
					XI. Limited availability of platforms to publicise LCA concept					
					Any other negative factor observed other than above findings					

14. Identify suitable strategies as a solution for negative factors
……
……
……
…………………………………….

I would like to thank you for the information given and the time you have dedicated to this research.

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