

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

Sedillage Don Isuri Anuradha Amarasinghe

(198056X)

Thesis submitted in partial fulfilment of the requirements for the degree of
Master of Science by Research

Department of Building Economics

University of Moratuwa

Sri Lanka

September 2020

DECLARATION

Declaration, Copyright Statement and the Statement of the Supervisor

“I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Further, I acknowledge the intellectual contribution of my research supervisors Dr. Chandanie Hadiwattege for the successful completion of this research thesis. I affirm that I will not make any publication from this research without the names of my research supervisors as contributing authors unless otherwise, I have obtained written consent from my research supervisors.

Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books)”.

Signature of the Student:

.....

Date.....

Amarasinghe S.D.I.A

The above candidate has carried out research for the MSc Thesis under my supervision.

Signature of the Supervisors:

.....

Date.....

Dr. Chandanie Hadiwattege

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*

ACKNOWLEDGMENT

The successful completion of my MSc thesis is not a single attempt that was taken by me. Therefore, I make this an opportunity to express my sincere gratitude to every individual who encouraged and supported me by giving their assistance for the successful completion of this research.

First and foremost I would like to convey my sincere gratitude to Dr. Chandanie Hadiwattege for her supervision, guidance, and encouragement to make this research successful as my supervisor. I would like to extend my sincere gratitude to all the academic and non-academic staff of the Department of Building Economics for their immense assistance provided during the research period.

Further, I wish to extend my sincere gratitude to Senate Research Committee of the University of Moratuwa for providing funding to undertake this research under SRC/LT/2019/23. My sincere gratitude is extended to all the interviewees who supported throughout the data collection process in this research and assisted in many ways to deliver the final outcome of this study.

Moreover, I would like to convey my respectable gratitude to my family members. Finally, my appreciation goes to all my friends who have helped me directly and indirectly to make this research a success.

TABLE OF CONTENTS	
DECLARATION.....	I
ABSTRACT.....	II
ACKNOWLEDGMENT	III
TABLE OF CONTENTS	IV
LIST OF TABLES	IX
TABLE OF FIGURES.....	XI
LIST OF ABBREVIATIONS	XIII
CHAPTER ONE	1
1.0 INTRODUCTION.....	1
1.1 Background	1
1.2 Problem Statement	4
1.3 Aim and Objectives	5
1.4 Research Methodology.....	5
1.5 Scope and Limitations.....	6
1.6 Chapter Breakdown.....	7
1.7 Chapter Summary.....	8
CHAPTER TWO	9
2.0 LITERATURE REVIEW	9
2.1 Introduction	9
2.2 Life Cycle Assessment: A Tool for Assessing Environmental Impacts	9
2.2.1 Significance of LCA Application in the Construction Industry	10
2.2.2 LCA Applications in the Construction Industry.....	11

2.2.3 The Status of LCA Application in the Construction Industry of Developed and Developing countries	12
2.3 Factors Influencing the LCA Application in the Construction Industry	13
2.3.1 Positive Factors Influencing on LCA Application in the Construction Industry	13
2.3.2 Negative Factors Influencing on LCA Application in the Construction Industry	18
2.4 Establishing LCA in the Construction Industry: Key Stakeholders.....	21
2.5 Intermingling Key Stakeholders towards LCA Establishment in the Construction Industry: An Innovational Approach.....	22
2.5.1 Evolution of Helix Innovation Models	24
2.5.2 Quintuple Helix Innovation Model.....	26
2.5.3 Modifying Quintuple Helix Model.....	28
2.6 Aligning essential contextual stakeholders for establishing LCA in the construction industry with the Quintuple Helix Innovation Model significant contenders.....	30
2.7 Conceptual Quintuple Helix Innovation Model for LCA Integration to the Construction Industry	31
2.8 Summary	31
CHAPTER THREE	34
3.0 RESEARCH METHODOLOGY	34
3.0 Introduction	34
3.1 Research Design.....	34
3.2 Research Approach.....	34
3.3 Research Strategy.....	36

3.4 Research Techniques.....	37
3.4.1 Data Collection Technique	37
3.4.2 Sampling Technique	41
3.4.3 Data Analysis Technique.....	45
3.5 Decision criteria for categorising strengths/opportunities and weaknesses/threats	46
3.6 Chapter Summary	48
CHAPTER FOUR.....	49
4.0 DATA ANALYSIS AND DISCUSSION.....	49
4.1 Introduction	49
4.2 Analysis and Discussion of the Research Findings.....	49
4.3 Environmental Impacts Generated by the Construction Industry	49
4.4 Importance of Managing Environmental Impact in the Sri Lankan Construction Industry.....	51
4.5 Introducing LCA as an Environmental Management Tool for the Sri Lankan Construction Industry	53
4.6 Strengths/Opportunities and Weaknesses/Threats for Establishing Life Cycle Assessment in the Sri Lankan Construction Industry	54
4.8 Contenders in the Quintuple Helix Innovation Model: Academia.....	55
4.8.1 Strengths and Opportunities in Establishing LCA in the Construction Industry: Academia	55
4.8.2 Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Academia	59
4.8.3 Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Academia	62

4.9	Contenders in the Quintuple Helix Innovation Model: Government	64
4.9.1	Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Government	65
4.9.2	Weaknesses and Threats in Establishing Life Cycle Assessment for the Construction Industry: Government	69
4.9.3	Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Government	74
4.10	Contenders in the Quintuple Helix Innovation Model: Construction Industry	76
4.10.1	Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Construction Industry	76
4.10.2	Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Construction Industry	80
4.10.3	Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Construction Industry	84
4.11	Contenders in the Quintuple Helix Innovation Model: Society	87
4.11.1	Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Society	87
4.11.2	Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Society	91
4.11.3	Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Society	95
4.12	Contenders in the Quintuple Helix Innovation Model: Environmentalists	96
4.13.1	Strengths and Opportunities in Establishing Life Cycle Assessment in the Construction Industry: Environmentalists	97
4.13.2	Weaknesses and Threats in Establishing Life Cycle Assessment in the Construction Industry: Environmentalists	101

4.13.3 Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Environmentalists	104
4.14 A modified Quintuple Helix Innovation Model integrating the Significant Contender Roles and Strategies for LCA Integration to the Construction Industry ..	106
4. 15 Summary	116
CHAPTER FIVE	117
5.0 CONCLUSIONS AND RECOMMENDATIONS.....	117
5.1 Introduction	117
5.2 Conclusions Drawn from the Study	117
5.3 Contribution to the Knowledge	121
5.4 Limitations of the Study	121
5.5 Recommendations for Industry Practitioners	122
5.6 Recommendations for Academic Research.....	123
5.7 Summary	123
Annexure	124
References	128

LIST OF TABLES

Table 2.1: Positive Factors Faced by Different Stakeholders for Establishing LCA in the Construction Industry.....	14
Table 2.2: Negative Factors Faced by Different Stakeholders in establishing LCA for the Construction Industry.....	18
Table 2.3: Role of Contenders in the Quintuple Helix Innovation Model.....	26
Table 3.1: A Comparison of the Quantitative Approach and the Qualitative Approach with the Requirements of this Study.....	355
Table 3.2: Types of Research Strategies.....	36
Table 3.3: Profile of Interviewees.....	44
Table 4.1: Repertory Grid for the Strengths and Opportunities in Establishing LCA in the Sri Lankan Construction Industry: Academia.....	55
Table 4.2: Repertory Grid for the Weaknesses and Threats in Establishing LCA in the Sri Lankan Construction Industry: Academia.....	59
Table 4.3: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Academia.....	63
Table 4.4: Repertory Grid for the Strengths and Opportunities for Establishing LCA in the Sri Lankan Construction Industry: Government.....	65
Table 4.5: Weaknesses and Threats in Establishing LCA for in Construction Industry: Government.....	69
Table 4.6: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Government.....	74
Table 4.7: Repertory Grid for the Strengths and Opportunities in Establishing LCA in the Sri Lankan Construction Industry: Construction Industry.....	76
Table 4.8: Repertory Grid for the Weaknesses and Threats in Establishing LCA in the Sri Lankan Construction Industry: Construction Industry.....	81
Table 4.9: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Construction Industry.....	85

Table 4.10: Repertory Grid for the Strengths and Opportunities in establishing LCA in the Sri Lankan Construction Industry: Society	87
Table 4.11: Repertory Grid for the Weaknesses and Threats in Establishing LCA in the Sri Lankan Construction Industry: Society	91
Table 4.12: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Society	95
Table 4.13: Repertory Grid for the Strengths and Opportunities in Establishing LCA in the Sri Lankan construction industry: Environmentalists	977
Table 4.14: Repertory grid for the weaknesses and threats in establishing LCA in the Sri Lankan Construction Industry: Environmentalists	101
Table 4.15: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry: Environmentalist	1055

TABLE OF FIGURES

Figure 2.1: Three Types of Helix Models.....	25
Figure 2.2: Developed Quintuple Helix Model for a Green New Deal	288
Figure 2.3: Conceptual Quintuple Helix Innovation Model for Establishing LCA in Construction Industry.....	33
Figure 3.1: Concept of SWOT Analysis	39
Figure 3.2: Components in the Repertory Grid Interview Technique	41
Figure 3.3: Selection Process of the Sampling Method.....	43
Figure 3.4: Decision Criteria for Categorising Strengths and Opportunities.....	437
Figure 3.5: Decision Criteria for Categorising Weaknesses and Threats	437
Figure 4.1: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Academic Perspective	62
Figure 4.2: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from the Government Perspective	73
Figure 4.3: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry	84
Figure 4.4: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from a Society Perspective.....	944
Figure 4.5: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Environmentalists Perspective	104
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	1049
Figure 4.7: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Academic Perspective	104
Figure 4.8: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from the Government Perspective	10411

Figure 4.9: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry 10412

Figure 4.10: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from a Society Perspective..... 10413

Figure 4.11: SWOT Analysis to Establish LCA for the Sri Lankan Construction Industry from an Environmentalists Perspective 10414

Figure 4.12: Strategies to Overcome Weaknesses and Threats in Establishing LCA in the Construction Industry..... 10415

LIST OF ABBREVIATIONS

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