Ain Shams University

Faculty of Engineering

Structural Engineering Department

LIFE CYCLE ASSESSMENT OF SUSTAINABLE CONSTRUCTION

BY

ABDELRAHMAN AMEEN ABDELMONEM

B.Sc., Civil Engineering

Mansoura University, 2013

A Thesis

Submitted in Partial Fulfillment for the Requirements of the Degree of Master of Science in Structural Engineering

Supervised by

Dr. MONA MOSTAFA

Associate Professor in Structure Engineering Dept.

Faculty of Engineering – Ain Shams University

Dr. MOHAMED EL-MIKAWI

Associate Professor in Structure Engineering Dept.

Faculty of Engineering – Ain Shams University

Dr. AYMAN MOSALLAM

Professor of Civil & Environment Engineering.

The University of California-vine, (UCI)

2019

Ain Shams University

Faculty of Engineering

Structural Engineering Department

LIFE CYCLE ASSESSMENT OF SUSTAINABLE CONSTRUCTION

BY

ABDELRAHMAN AMEEN ABDELMONEM

B.Sc., Civil Engineering

Mansoura University, 2013

A Thesis

Submitted in Partial Fulfillment for the Requirements of the Degree of Master of Science in Structural Engineering

Supervised by

Dr. MONA MOSTAFA
Associate Professor in Structure Engineering Dept.
Faculty of Engineering – Ain Shams University

Dr. MOHAMMED EL-MIKAWI
Associate Professor in Structure Engineering Dept.
Faculty of Engineering – Ain Shams University

Dr. AYMAN MOSALLAM
Professor of Civil & Environment Engineering.
University of California, Ir-vine, (UCI)

2019

Ain Shams University

Faculty of Engineering

Structural Engineering Department

APPROVAL SHEET

Thesis: Master of Science in Civil Engineering (Structural)

Researcher Name: Abdelrahman Ameen AbdElmonem

Thesis Title: Life Cycle Assessment of Sustainable Construction

Examiners Committee	Signature
Prof. Manal Sayed Abdelhamid Professor in Construction and Project Management Research Institute Housing & Building National Research Center, HBRC	.....
Prof. Ali Sherif Abdelfayad Professor Structure Engineering Structural Engineering Dept. Faculty of Engineering –Ain Shams University	.....
Dr. MOHAMMED MIKAWI Associate Professor in Structure Engineering Structural Engineering Dept. Faculty of Engineering –Ain Shams University	.....
Dr. AYMAN MOSALLAM Professor of Civil & Environment Engineering. University of California, Ir-vine, (UCI)	.....

Ain Shams University

Faculty of Engineering

Structural Engineering Department

Thesis: Master of Science in Civil Engineering (Structural)

Researcher Name: Abdelrahman Ameen AbdElmonem

Thesis Title: Life Cycle Assessment of Sustainable Construction

Supervision Committee	Signature
Dr. Mona Mostafa Associate Professor in Structure Engineering, Structural Engineering Dept. Faculty of Engineering –Ain Shams University	.....
Dr. MOHAMMED MIKAWI Associate Professor in Structure Engineering Structural Engineering Dept. Faculty of Engineering –Ain Shams University	.....
Dr. AYMAN MOSALLAM Professor of Civil & Environment Engineering. University of California, Ir-vine, (UCI)	.....

STATEMENT

This thesis is submitted as partial fulfillment of Master of Science in Civil Engineering (Structural Engineering), Faculty of Engineering Ain Shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or qualification at any other scientific entity.

Student name
Abdelrahman Ameen
Signature
……
Date: …….

INFORMATION ABOUT THE RESEARCHER

Name: Abdelrahman Ameen AbdElmonem

Date of birth: 01 May 1991

Place of birth: Damietta City, Egypt

Email: Abdelrahman.ameen@hpd.com.eg

Mobile: 01012184774

Last academic degree: Bachelor of Science

Field of specialization: Structural Engineering

University issued the degree: Ain Shams

Date of issued degree:

Current job: Structural Engineer at Hyde Park Properties for Development, Egypt.

ABSTRACT

Life cycle assessment (LCA) has become an essential tool to determine the environmental impacts of construction materials and products. LCA is a very effective strategy in analyzing the impact of different structures during its life cycle, considering economic, environmental, and sustainability aspects. The use of this technique helps structural engineers, contractors, and owners in predicting environmental impacts throughout the structure's life cycle. LCA is an essential tool which encourages civil and structural engineers to reduce the embodied energy of any structure. The major stages of LCA study are raw material acquisition, materials manufacture, production, use/reuse/maintenance, and waste management.

Recently, the Ministry of Housing and the Housing & Building National Research Center (HBRC) in Egypt have shown great attention to this topic. This is demonstrated by the establishment of the National Council for Housing Minister Green Architecture to develop policies that lead to the dissemination and application of the idea of green architecture. Nowadays, several manufacturers have developed a new technique called “3D panel system" (i.e., Enbuil panel system, EPS) which is recommended for low rise buildings (up to three stories height).

This research aims to emphasize the value added to the construction sector by using EPS during the construction phases.

A case study is used to demonstrate the benefits of the proposed system by comparing its environmental impacts with that of the traditional reinforced concrete system (materials/methods). The software ATHENA Impact Estimator is used to compute the environmental impacts for the two systems.

The study results related to the environmental impacts highlight that the EPS system is (70-80) % lower than the traditional system with a significant reduction in fossil fuel consumption by (70-85) %. A cost-time study is performed using Primavera software that concludes that the EPS system has lower cost and time impacts by 25% and 45%, respectively than the traditional system.

A cost-time study is performed using Primavera software concludes that the total initial cost of EPS system is approximately lowering than the cost of R.C. system by (20-25) %, as the amounts of reinforcement steel and cement of EPS system decrease of about 50 % and 32 % respectively, if compared to R.C. system. The study also indicated that a significant reduction in construction time with a range (45-60) % could be achieved when using the EPS system as an alternative to the traditional reinforced concrete/bricks system.

Keywords: Life cycle, Egyptian market, Environmental impacts, EPS system, 3D panel system.

ACKNOWLEDGMENTS

Thanks are due to GOD for the gracious and mercy of blessing me with patience and knowledge to finish this work.

The author would like to express his sincere gratitude to ***Dr. Ayman Mosallam,*** Professor of Civil & Environment Engineering.

University of California, Ir-vine,(UCI), for supervision, generous and intellectual support, encouragement, and advice throughout this research.

The author is indebted to ***Dr. Mohammed Mikawi,*** Assistant Professor of structure Engineering, Department of Structural Engineering, Faculty of Engineering, Ain Shams University and The author is grateful to ***Dr. Mona Mostafa,*** Assistant Professor of structure Engineering, Department of Structural Engineering, Faculty of Engineering, Ain Shams University for patient review of this manuscript.

I would like to thank the rest of the Thesis committee

Finally, I want to thank my family for their love, understanding, endless patience, and encouragement.

Abdelrahman Ameen Abdelmonem

Cairo, 2019

Contents

STATEMENT **IV**
ABSTRACT **1**
ACKNOWLEDGMENTS **3**
LIST OF FIGURES **8**
LIST OF TABLES **11**
LIST OF ABBREVIATION **12**
INTRODUCTION **14**
1.1. General **14**
1.2. Problem statement **16**
1.3. Research Objectives and Scope **16**
1.4. Thesis Organization **17**
CHAPTER (2) **20**
BACKGROUND AND LITERATURE REVIEW **20**
2.1. Introduction **20**
2.2. Sustainable development concept **20**
2.3. Life Cycle Assessment concept and principles **21**
2.4. Life Cycle Assessment scope **22**
2.5. Life Cycle Assessment Procedures **24**
2.6. Life cycle assessment stages **25**
2.6.1. 25
2.7. Environmental impacts **26**
2.7.1. Acidification Potential 26
2.7.2. Eutrophication 28
2.7.3. Stratospheric ozone depletion (ODP) 29
2.7.4. Smog potential 30
2.7.5. Global warming potential 31
2.7.6. Comparison of Human Health particulate by life cycle stage: 34
2.7.7. Fossil Fuel Consumption 35
2.8. History of Sustainable Buildings **35**
2.8.1. The Buildings of Mud 36
2.8.2. Buildings of Sandbags 37
2.8.3. Sandwich Panel System 38
2.9. Related Researches Work: **40**
CHAPTER (3) **48**
INTERNATIONAL ENVIRONMENTAL ASSESSMENT RATING SYSTEMS WITH A COMPARISON BETWEEN THEM AND GREEN PYRAMID RATING SYSTEM **48**
3.1. Introduction **48**
3.2. Environmental impacts during the construction phases **50**
3.3. Building Research Establishment's Environmental Assessment Method (BREEAM) **57**

3.3.1. Background: 57
3.3.2. BREEAM objective 57
3.3.3. Assessment Categories 58
3.3.4. BREEAM Scoring System: 60
3.3.5. Assessment Process 60
3.4. CASBEE 62
3.4.1. Background 62
3.4.2. Assessment Categories 62
3.4.3. Assessment Process 63
3.4.4. CASBEE Objective 64
3.4.5. CASBEE Scoring System 65
3.5. LEED 68
3.5.1. Background 68
3.5.2. Assessment Categories 68
3.5.3. LEED Scoring System 69
3.5.4. Assessment Process 70
3.5.5. LEED Objective 70
3.6. GREEN STAR RATING SYSTEM 70
3.6.1. Background 70
3.6.2. Green Star objective 71
3.6.3. Assessment Categories 71
3.6.4. Green Star Scoring System 72
3.6.5. Assessment Process 73
3.7. GREEN PYRAMID RATING SYSTEM 75
3.7.1. Background 75
3.7.2. Assessment Categories 76
3.7.3. Assessment Process 76
3.7.4. Scoring System 77
3.7.5. Example of Green Pyramid Rating System 77
3.8. SUMMARY OF SUSTAINABLE RATING SYSTEMS 79
3.8.1. System Maturity Objectives 79
3.8.2. Usability objectives 80
3.8.3. Applicability objectives 81
3.8.4. Communicability 82
3.8.5. Technical comparison objectives 82
CHAPTER (4) 84
CRITERIA OF SUSTAINABLE MATERIAL SELECTION AND ENBUIL PANEL SYSTEM 84
4.1.Introduction 84
4.2. Sustainable building materials selection methodology 86
4.2.1. Criteria 86
4.2.2. Pre-construction stage (Assembling process) 87

4.2.3. Construction stage: Use 88
4.2.4. Post construction stage: Disposal 89
4.3. Cementitious Sandwich Panel System (CSP) 90
4.3.1. History of the cementitious sandwich panel 90
4.4. Cementitious Sandwich Panel System characteristics 94
A. EPS Foam Characteristics 96
B. Mortar Characteristics 98
C. Steel Wire Mesh 99
4.5. Conclusion Error! Bookmark not defined.
CHAPTER (5) 106
ENBUIL TRIDIPANEL SYSTEM BUILDING SYSTEM IN EGYPT: A CASE STUDY 106
5.1. Introduction 106
5.2. Assembly of Enbuil-Tridipanel´s 107
A. V. Openings 109
B. Wall and roof connection 112
C. Utilities 114
D. Columns and Beams 116
E. Application of Cementitious Skins 117
5.3. Case Study Assumption 120
5.4. Case Study Objectives 121
5.5. Methodology 122
5.6. Simulation Software 123
A. The Athena Impact Estimator 123
B. Primavera software 124
5.7. Case study (1) Bedouin low-income house 125
5.7.1. Choosing Criteria 125
5.7.2. Case Study Overview 126
5.7.3. Modeling of spaces under study 128
5.8. 129
5.8. Case study (2) Build your home 129
5.8.1. Case Study Criteria 129
5.8.2. Case Study Overview 130
CHAPTER (6) 133
CASE STUDY RESULTS AND DISCUSSION 133
6.1. Introduction 133
6.2. Environmental Impacts Analysis 134
6.2.1. Comparison of acidification potential by life cycle stage 134
6.2.2. Eutrophication (EP) 136
6.2.3. Stratospheric ozone depletion (ODP) 138
6.2.4. Smog potential (Also known as photochemical ozone creation) 140
6.2.5. Global warming potential 142

6.2.6. Fossil fuel consumption 144
6.2.7. Emissions to land life cycle inventory 146
6.2.8. Emissions to Air 148
6.3. Cost analysis 150
6.4. Time impact 153
155
6.5. Discussion 156
7.1. CONCLUSION 160
7.2. RECOMMENDATIONS FOR FUTURE RESEARCH 163
REFERENCES 165
APPENDICES I

LIST OF FIGURES

Figure 2. 1: The life cycle of a building element showing the inputs and outputs examined by LCA.....26

Figure 2. 2: Acidifying Phenomena showing main gases responsible for acidifying pollution.....27

Figure 2. 3: Eutrophication Phenomena showing emissions of nitrates and phosphates leads to ecosystems damages.....28

Figure 2. 4: Ozone depletion phenomena 30

Figure 2. 5: Photochemical ozone creation 31

Figure 2. 6: Global warming potential phenomena.....32

Figure 2. 7: Hassan Fatty's Mud Architecture (Wafa, n.d.) 37

Figure 2. 8: Stress strain diagram (Ehsan mirnateghi 2016). 38

Figure 2. 9: Components of Cementitious sandwich panel system 39

Figure 3. 1: Breakdown in BREEAM Office 2008 Points, ...59

Figure 3. 2: BREEAM Assessment process.....61

Figure 3. 3: Division of the assessment categories for CASBEE.....64

Figure 3. 4: Labeling Based on Built Environment Efficiency (BEE).....65

Figure 3. 5: CASBEE scoring system office 2008 points 67

Figure 3. 6: CASBEE examples.....68

Figure 3. 7: Breakdown of GREEN STAR points.....72

Figure 3. 8: GREEN STAR scoring and weighting (Hassan, 2009).....74

Figure 3. 9: GPRS Assessment Category (Aleem, Zobaa, and Mageed 2015).....76

Figure 3. 10: GPRS calculation example.....78

Figure 4. 1: Components of a cementitious sandwich panel system (mimatghi, 2017). 92

Figure 4. 2: Components of the sandwich panel with parallel connectors (mimatghi, 2017).....92

Figure 4. 3: SIPs sandwich panel system (mimatghi, 2017). 93

Figure 4. 4: Conventional Wire Mesh 1:1 Grid Face (mimatghi, 2017).....99

Figure4.5: Stress-strain curve for 1:1 grid mesh (mimatghi, 2017). 100