INTEGRATION OF THE DISASTER RISK REDUCTION (DRR) AND DISASTER RESILIENCE MECHANISMS INTO THE GREEN BUILDING RATING SYSTEMS - CASE STUDY ON THE GREEN SL RATING SYSTEM OF SRI LANKA

A.A.S.E. Abeysinghe

(198111M)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

September 2020

INTEGRATION OF THE DISASTER RISK REDUCTION (DRR) AND DISASTER RESILIENCE MECHANISMS INTO THE GREEN BUILDING RATING SYSTEMS - CASE STUDY ON THE GREEN SL RATING SYSTEM OF SRI LANKA

Abeysinghe Arachchige Sonali Erandi Abeysinghe

(198111M)

Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

April 2020

Declaration of the Candidate & Supervisors

I declare that this is my own work and this thesis/dissertation 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.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, 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: UOM Verified Signature Date: 25th September 2020

The above candidate has carried out research for the Master's thesis under my supervision.

Name of the supervisor: Dr. C.S.A. Siriwardana

Signature of the supervisor: UOM Verified Signature Date: 28th September 2020

Name of the supervisor: Prof. P.B.R. Dissanayake

Signature of the supervisor: UOM Verified Signature Date: 28th September 2020

Name of the supervisor: Dr. C.S. Bandara

Signature of the supervisor: UOM Verified Signature Date: 28th September 2020

Abstract

The rapid growth of global human population necessitates the facilitation of increased number of buildings and other infrastructure. Primarily in economically developing nations, these buildings are designed only complying with local level regulations and standards which are outdated and not carrying allowance for disaster risk reduction and climate changes such as global warming. In the context of Sri Lanka, unplanned developments and expansions due to urbanization has made the community and their assests and resources vulnerable to natural hazards like floods, landslides, tsunami, droughts, coastal erosion and cyclones. Out of them, floods, landslides, heavy winds and Tsunamis have caused the highest number of damages to buildings and loss of human lives during the period of 1965 to 2019 and hence can be considered as significant in providing action.

Since anthropogenic natural hazards have kicked off to occur more frequently, it is vital to erect buildings, especially community shelters, in a way that they can withstand strains and pressures that will be imposed by changing future trends. Striving to achieve its vision, the Green Building Council of Sri Lanka (GBCSL) is playing a commendable role in maximizing Sri Lanka's greener practices and sustainability through the development of green rating tools for buildings and infrastructure, recognition of green materials to be used as construction materials and conducting professional training programs, green talks, workshops and many CSR activities. It has inculcated sustainability and resilience in their rating systems and practices, through enhancing the usage of locally manufactured and less energy consumed material and reducing resource and energy consumption in buildings, it has not yet been properly recognized the need to inculcate the Disaster Risk Reduction (DRR) mechanisms in to their rating systems. Therefore, to ensure an economically viable, environmentally-friendly and socially recognized growth in Sri Lanka, it's high time that the sustainable disaster risk reduction and mitigation measures are incorporated in the design, construct and operation phases of buildings.

Thus, this study was carried out to incorporate the DRR and disaster resilience structural and non-structural mechanisms for floods, landslides and heavy winds into the existing categories of the rating tools for buildings, cities and transportation infrastructure of the GREEN SL Rating System for Built Environment in Sri Lanka in transforming the existing construction industry of Sri Lanka into a disaster resilient and a sustainable one.

Key Words: Natural Hazards; Disaster Risk Reduction; Green Buildings; Disaster Resilient Buildings

Acknowledgements

I would like to extend my sincere gratitude to my research supervisors, Dr. Chandana Siriwardana, Prof. Ranjith Dissanayake and Dr. Chaminda Bandara for their guidance, suggestions and motivation throughout the research work.

Also, I would like to express my appreciation to the Research Coordinator of the Department of Civil Engineering, University of Moratuwa; Dr. Kumari Gamage and the panel head of my review panel Dr. Nimal Wijayaratna lead research work towards a successful completion.

Our sincere special thanks should go to the Ms. Samantha Manawadu, Mr. Mihiran Mapalagama and the directors and green accredited professionals of Green Building Council of Sri Lanka (GBCSL) for providing me with the necessary information and their expertise knowledge to carry out research work effectively within the given time. Also, my appreciation goes to Prof. Dilanthi Amarathunga and Prof. Richard Haigh of University of Huddersfield, UK for their expert knowledge and inputs in making my research study a success.

Finally, I would like express my gratitude to all the professionals, private and public organizations who assisted us to carry out the questionnaire surveys and discussions to gather information related to the topic from the stakeholders and also to all my colleagues for their support and encouragement throughout this research study.

Thank You,

A.A.S.E. Abeysinghe

Table of Contents

Declaration of the Candidate & Supervisors i

Abstract ii

Acknowledgements iii

Table of Contents iv

List of Figures vi

List of Tables vii

List of Equations viii

List of Examples ix

1 INTRODUCTION 1

1.1 Context 1

1.2 Research Gap 8

1.3 Research Scope 8

1.4 Research Question 10

1.5 Objectives 10

2 LITERATURE 11

2.1 Introduction to Disaster Risk Reduction & Disaster Management 11

2.2 Global Frameworks for Disaster Risk Reduction 13

2.3 Green Building Councils and Green Rating Systems 20

2.3.1 Leadership in Energy and Environmental Design (LEED) by United State's Green Building Council (USGBC) 24

2.3.2 RELi Rating System by U.S. Green Building Council 28

2.3.3 Comprehensive Assessment System for Built Environment Efficiency (CASBEE) by Japanese Green Building Council (JGBC) 36

2.3.4 GREENSHIP Rating System by Green Building Council of Indonesia 40

2.3.5 Building for Ecologically Responsive Design Excellence (BERDE) by Green Building Council of Philippines 43

2.4 GREENSL® Rating Systems for Built Environment 45

2.5 Disaster Risk Reduction (DRR) Mechanisms and Disaster Resilient Local Guidelines 51

2.5.1 Structural (Hard) DRR Measures 51

2.5.2 Non - Structural (Soft) DRR Measures 66

3 METHODOLOGY 70

3.1 Development and Incorporation of Guidelines ……70

3.2 Evaluation of the Incorporated Guidelines ……76

3.3 Awarding of Credit ……78

3.4 Applicability Evaluation and Validation ……83

4 RESULTS AND ANALYSIS ……85

5 FUTURE WORK ……102

5.1 Development and Incorporation of DRR and Disaster Resilient Mechanisms into the City Tool and the Transportation Infrastructure Tool of GREENSL Rating System for Built Environment Conclusions……102

6 CONCLUSIONS AND RECOMMENDATIONS …… 103

6.1 Conclusions……103

6.2 Recommendations……104

Reference List ……105

Annex 1: Building Tool of the GREENSL® Rating System for Built Environment Incorporated with DRR and Disaster Resilient Mechanisms ……109

Annex 2: Transportation Infrastructure Tool of the GREENSL® Rating System for Built Environment Incorporated with DRR and Disaster Resilient Mechanisms ……212

Annex 3: City Tool of the GREENSL® Rating System for Built Environment Incorporated with DRR and Disaster Resilient Mechanisms ……273

Annex 4: Journal Publication, Springer Nature Singapore Pte Ltd., 2021 (To be published) ……308

Annex 5: Conference Publication, International Symposium of Multi Hazard Early Warning Systems, Colombo Sri Lanka, March 2020 (Postponed)……323

Annex 6: Conference Publication, International Conference of Sustainable Built Environment, December 2020, Kandy, Sri Lanka (Abstract Submitted) ……324

Annex 7: Conference Publication, 9th International Conference of Building Resilience, Bali, Indonesia, January 2020 ……325

Annex 8: Journal Publication, International Journal of Disaster Resilience in the Built Environment, January 2020 ……348

Annex 9: Conference Paper, International Conference on Sustainable Built Environment - Malta, November 2019 ……371

Annex 10: Conference Paper, International Conference on Building Resilience – Indonesia, January 2020……382

List of Figures

FIGURE 1: VARIATION OF FIVE RISK CATEGORIES BASED ON IMPACT AND LIKELIHOOD 2
FIGURE 2: GLOBAL RISKS FROM 2009 TO 2019 (SOURCE: WORLD ECONOMIC FORUM RISK PERCEPTION SURVEY 2018-2019, [2]) 3
FIGURE 3: NATIONALLY REPORTED ECONOMIC LOSSES (1990-2014) [7] 6
FIGURE 4: WORLD RISK INDEX (2016) BY IRDR|HTTP://WWW.IRDRINTERNATIONAL.ORG 9
FIGURE 5: DISASTER MANAGEMENT CYCLE [28] 13
FIGURE 6: IPCC RISK CONCEPTUAL FRAMEWORK 14
FIGURE 7: CLASSIFICATION OF GREEN BUILDING COUNCILS BY WORLDGBC 21
FIGURE 8: SHORTER SIDE OF THE BUILDING IS ORIENTED TO FACE THE DIRECTION OF FLOODING [61] 52
FIGURE 9: PLACEMENT OF OPENINGS IN BUILDINGS, CREATING A FLOW PATH FOR WATER [61] 52
FIGURE 10: PLINTH LEVEL RAISED BY BUILDING ON HIGHER GROUND [61] 53
FIGURE 11: PLINTH LEVEL RAISED BY CREATING AN ELEVATED GROUND [61] 53
FIGURE 12: PLINTH LEVEL RAISED BY BUILDING ON SILTS [61] 54
FIGURE 13: CROSS WALLS [61] 54
FIGURE 14: HEIGHT OF THE CUT SLOPE IS EQUAL TO THE DISTANCE BETWEEN BUILDING AND CUT SLOPE [61] 58
FIGURE 15: RELATIONSHIP BETWEEN HEIGHT OF THE RETAINING WALL AND THE DISTANCE BETWEEN RETAINING WALL [61] 59
FIGURE 16: TERRACED BUILDING [61] 61
FIGURE 17: AN ELEVATED STRUCTURE ON COLUMNS OR RAISED FOOTINGS [61] 61
FIGURE 18: WIND LOADING AND ZONATION MAP OF SRI LANKA [13] 63
FIGURE 19: SHORTER SIDE OF THE BUILDING FACING WIND DIRECTION [61] 64
FIGURE 20: OPENINGS ON OPPOSITE WALLS CREATING FLOW PATH [61] 64
FIGURE 21: BRICKWORK CONSTRUCTION AROUND THE DOOR FRAME [61] 65

List of Tables

TABLE 1: SUMMARY OF DEATHS, HOUSES DESTROYED AND DAMAGED, AFFECTED VICTIMS AND LOCAL LOSSES FROM MAIN DISASTERS OCCURRED IN SRI LANKA (1965 - 2019) [8] 5
TABLE 2: DRR AND DISASTER RESILIENT MECHANISMS INCORPORATED IN THE LEED V 4.1 FOR . NEW CONSTRUCTION AND DESIGN RATING TOOL 27
TABLE 3: DRR AND DISASTER RESILIENT MECHANISMS INCORPORATED IN TO THE RELI 2.0 RESILIENT TOOL [46] 30
TABLE 4: DRR AND DISASTER RESILIENT MECHANISMS INCORPORATED IN THE GREENSHIP NEW BUILDING VERSION 1.0 RATING TOOL 42
TABLE 5: IN-DEPTH DETAILS ABOUT PRE-REQUESTS AND CREDITS OF THE GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT V 2.0 FOR NEW BUILDING [37] 47
TABLE 6: DRR AND DISASTER RESILIENT MECHANISMS INCORPORATED IN TO THE GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT FOR NEW BUILDINGS VERSION RATING TOOL [37] 51
TABLE 7: THE STABLE CUT SLOPES IN DIFFERENT SOIL TYPES WITH OR WITHOUT A RETAINING WALL [61] 58
TABLE 8: EXPERT COMMITTEE FOR EVALUATION OF INCORPORATED GUIDELINES 76
TABLE 9: THE SCORE CARD OF THE CREDITED, DISASTER RESILIENT BUILDING TOOL OF THE GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT 79
TABLE 10: LIST OF BUILDINGS AND THEIR DETAILS WHICH ARE CHOSEN FOR THE VALIDATION SURVEY 84
TABLE 11: THE SCORE CARD FOR THE PROJECT A AT BADALGAMA USING THE DISASTER RESILIENT BUILDING TOOL OF THE GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT 85
TABLE 12: THE SCORE CARD FOR THE PROJECT C AT BADULLA USING THE DISASTER RESILIENT BUILDING TOOL OF THE GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT 89
TABLE 13: THE SCORE CARD FOR THE PROJECT F AT TRINCOMALEE USING THE DISASTER RESILIENT BUILDING TOOL OF THE GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT 92
TABLE 14: THE SCORE CARD FOR THE PROJECT I AT HOMAGAMA USING THE DISASTER RESILIENT BUILDING TOOL OF THE GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT 96
TABLE 15: SUMMARY TABLE OF THE ELEVEN SURVEYS CONDUCTED USING THE NEW DISASTER RESILIENT BUILDING TOOL OF GREENSL® RATING SYSTEM FOR BUILT ENVIRONMENT 100

List of Equations

EQUATION 1: RISK EQUATION BY CHAPMAN 11
EQUATION 2: RISK EQUATION BY GREOVE 11
EQUATION 3: RISK EQUATION BY RAFETRY 11
EQUATION 3: BEE VALUE CALCULATION EQUATION 37

List of Examples

EXAMPLE 1: LEVEL 03 - GUIDELINES ARE INCORPORATED AS A NEW MINOR IMPROVEMENT OR AN AMENDMENT DONE TO SUB-PREREQUISITES & SUB-CREDITS 73
EXAMPLE 2: LEVEL 01 - GUIDELINES ARE INCORPORATED AS A NEW SUBCATEGORY 74
EXAMPLE 3: LEVEL 02 - GUIDELINES ARE INCORPORATED AS A NEW SUB-PREREQUISITE OR A SUB-CREDIT.....75