



FRAMEWORK FOR OPTIMIZING SUSTAINABLE INFRASTRUCTURE BRIDGE PROJECTS

By

AHMED NOUH AHMED MESHREF

**A Thesis Submitted to
The Faculty of Engineering at Cairo University
in Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY
in
STRUCTURAL ENGINEERING**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2014**

FRAMEWORK FOR OPTIMIZING SUSTAINABLE INFRASTRUCTURE BRIDGE PROJECTS

By

AHMED NOUH AHMED MESHREF

A Thesis Submitted to
The Faculty of Engineering at Cairo University
in Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY
in
STRUCTURAL ENGINEERING

Under Supervision of

Prof. Dr.

Moheeb El-Said Ibrahim

Prof. Dr.

Mohamed Mahdy Marzouk

Professor of Construction Engineering
and Management
Structural Engineering Department
Faculty of Engineering
Cairo University

Professor of Construction Engineering
and Management
Structural Engineering Department
Faculty of Engineering
Cairo University

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
September-2014**

FRAMEWORK FOR OPTIMIZING SUSTAINABLE INFRASTRUCTURE BRIDGE PROJECTS

By

AHMED NOUH AHMED MESHREF

A Thesis Submitted to
The Faculty of Engineering at Cairo University
in Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY
in
STRUCTURAL ENGINEERING

Approved by Examining Committee:

Prof. Moheeb Elsaid Ibrahim -----
Professor of Construction Engineering and Management - Structural
Engineering Department - Cairo University - **Thesis Main Advisor**

Prof. Mohamed Mahdy Marzouk-----
Professor of Construction Engineering and Management - Structural
Engineering Department - Cairo University

Prof. Adel Ibrahim El-Dosouky -----
Professor of Construction Project Management - Structural Engineering
Department - Tanta University

Prof. Mohamed Abd El Latif Bakry -----
Manager of Strategic Management Department - Social Development Fund

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
September-2014**

Engineer's Name: Ahmed Nouh Ahmed Meshref
Date of Birth: 16/04/1980
Nationality: Egyptian
E-mail: ahmednouh80@yahoo.com
Phone:
Address:
Registration Date: 17/06/2008
Awarding Date: .../.../.....
Degree: Philosophy of Doctoral
Department: Structure Engineering Department



Supervisors:
Prof. Prof. Moheeb Elsaid Ibrahim
Prof. Mohamed Mahdy Marzouk

Examiners:
Prof. Prof. Moheeb Elsaid Ibrahim
Prof. Mohamed Mahdy Marzouk
Prof. Adel Ibrahim El-Dosouky
Prof. Mohamed Abd El Latif Bakry

Title of Thesis: FRAMEWORK FOR OPTIMIZING SUSTAINABLE
INFRASTRUCTURE BRIDGE PROJECTS

Key Words: Green bridges, Rating Systems, Simo's Procedure,
MOOMS.

Summary:

Proper development and operation of infrastructure projects, such as bridges and highways, can contribute significantly to the mission of sustainable development. This thesis introduces a key-list of gathered important criteria that affect the sustainability of bridge projects. The initial list of criteria has been identified by unstructured interviews. Then, structured interviews and questionnaire survey have been conducted to identify the final list that is deemed important in rating green bridges. Final criteria results from this thesis are used to develop a green bridge rating system to achieve sustainable development. Degree of importance and weights of these criteria are determined using Simo's procedure. Five classes of bridges are proposed to judge their status with respect to sustainability. This research proposes a conceptual instrument that measures the user-based assessment of material sustainability and validates decision-maker's perceptions in order to evaluate the contribution of characteristics in materials selection. The contribution of this research is the development of a framework that consists of two modules for selecting appropriate building materials in order to help decision-makers with the appropriate selection of conventional or green bridges materials. The modules of the framework are; materials sustainability score (MSS) module and multi-objective optimization (MOO) module. The proposed framework helps to pursue sustainable environmentally friendly practices when selecting of bridges materials based on the proposed rating system in this thesis regarding actual costs. A case study is presented to demonstrate the use of the proposed framework.

ACKNOWLEDGEMENTS

First, I would like to express my grateful full respect and many thanks to my parents for their continuous support and everything done for me. There are no thanking words that can express my appreciation for both of them for surrounding me with their care and love. I would specially dedicate this thesis to them. I would like to thank very much my supervisors. **Prof. Moheeb El-Said Ibrahim** for his great support and valuable advices, and special great thanks to **Prof. Mohamed Mahdy Marzouk** for surrounding me with their great experience and valuable knowledge. Also I would like to extend a special thanks to my examiners **Prof. Adel Ibrahim El-Desouky**, and **Prof. Mohamed Abd-Ellatif Bakry** for their valuable supervision, precious advice and continuous encouragements. I would like to express my thanks to all engineers and workers supported me from Arab Contractors Co., General Authority for Roads and Bridges, General Nile for Roads and Bridges, Cairo university staff, workers, and all the consultants for their friendly support and valuable information.

TABLE OF CONTENTS

LIST OF TABLES	v
LIST OF FIGURES	vi
ACKNOWLEDGEMENT	vii
NOMENCLATURE	viii
ABSTRACT.....	x

CHAPTER 1: INTRODUCTION

1.1 General.....	1
1.2 Sustainable Bridges: An Overview	1
1.3 Research Motivation	4
1.4 Research Objectives.....	4
1.5 Research Methodology	5
1.6 Scope of work	5

CHAPTER 2: LITERATURE REVIEW

2.1 General.....	8
2.2 Sustainability in Construction Projects.....	8
2.3 Current Sustainable Practices	9
2.3.1 Sustainable Design	9
2.3.2 Sustainable Construction.....	13
2.3.3 Sustainable Bridge Maintenance	14
2.4 Approaches to Green Building Concepts.....	16
2.4.1 Material Efficiency.....	16
2.4.2 Energy Efficiency.....	17
2.5 Green Building Life-Cycle Analysis	19
2.5.1 Background of LCA Applications.....	20
2.6 Existing Major Green Rating Systems.....	22
2.6.1 Leadership in Energy and Environmental Design (LEED®) - New Construction.....	23
2.6.2 Envision™ Rating System	24
2.6.3 GreenLITES Project Design Certification Program.....	25

2.6.4 Sustainable Highway Self-Evaluation Tool	25
2.6.5 Green Pyramids	26
2.7 Practices in Bridge Design, Construction, and Maintenance.....	27
2.8 Life Cycle Assessment Applications	29
2.8.1 Bridge LCA	29
2.8.2 Available LCA Tools	31
2.9 Academic Origin Sustainability Programs	32
2.10 Proposed Criteria that influence Sustainability of Bridges Projects.....	35
2.11 Multi Objective Optimization.....	37
2.11.1 An Overview	37
2.11.2 Multi Objective Optimization Methods	40
2.12 Summary.....	42

CHAPTER 3: GREEN BRIDGES RATING SYSTEM

3.1 General.....	43
3.2 General Philosophy.....	43
3.3 System Boundaries	44
3.4 Green Bridges Categories	45
3.4.1 Credits based on fundamental sustainability values.....	45
3.4.2 Credit weighting overview	46
3.5 Green Bridges Rating System Implementation	48
3.6 Green bridges credits and their general intent	48
3.7 Identification of Criteria	50
3.7.1 Structured Interviews	52
3.7.2 Interviews Participants	52
3.7.3 Interviews Results	55
3.8 Summary.....	61

CHAPTER 4: CRITERIA WEIGHTS ESTIMATION USING SIMO'S PROCEDURE

4.1 General.....	62
4.2 Criteria Weights Estimation Procedure	62
4.3 Description of Simo's procedure	63

4.4 Simo's Rating Criteria Weights	64
4.5 Summary	70

CHAPTER 5: GREEN BRIDGES MATERIAL SELECTION IMPLEMENTATION FRAMEWORK

5.1 General	71
5.2 Material Selection Approaches	71
5.3 Material Selection Procedure	72
5.4 Green Bridges Materials Data Sources	72
5.5 Green Bridges Credits Dimensions for Materials Selection	73
5.5.1 Interview Survey (B) Results	73
5.5.2 Interview Survey (C) Results	75
5.6 Sustainable Materials Overview	76
5.7 Summary	82

CHAPTER 6: OPTIMIZING GREEN BRIDGES MATERIAL SELECTION

6.1 General	83
6.2 Case Study Overview	83
6.2.1 Case Description	83
6.3 Single Objective Optimization Material Selection (SOOMS)	89
6.3.1 Model Inputs	89
6.3.2 SOOMS Model Implementation	90
6.3.3 SOOMS Model outputs	91
6.4 Multi Objective Optimization Material Selection MOOMS	94
6.4.1 Model Inputs	94
6.5 MOOMS Model Outputs	96
6.6 Summary	100

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

7.1 Results and Conclusions	101
-----------------------------------	-----

7.2 Research Limitations	102
7.3 Research Contribution	102
7.4 Recommendations for Future Work	103
REFERENCES	104

APPENDICES

APPENDIX (A): PREVIOUS GREEN BUILDINGS EFFORTS	110
APPENDIX (B): INTERVIEWS SURVEYS & EXPERT PARTICIPANTS CONTACTS.....	135
APPENDIX (C): SUSTAINABILITY SCORE IDENTIFICATION CALCULATIONS & BEES MATERIALS LIST	151
APPENDIX (D): (SOOMS) EVOLOVER LOG OUTPUTS and (MOOMS), MATLAB CODES AND LOG OUTPUTS	165

LIST OF TABLES

Table No.	Title	Page
Table 2.1	: Embodied Energy and CO2 Levels for Steel.....	11
Table 2.2	: US Department of Energy-Energy Efficiency and Renewable Energy. Suggested Insulation Types	18
Table 2.3	: Previous Efforts in Green Buildings Design	21
Table 2.4	: LEED V.3 Certification Levels	23
Table 2.5	: GHG Impact Tools	32
Table 2.6	: Proposed criteria that influence Sustainability of Bridges Projects	36
Table 3.1	: Proposed Credits for Green Bridges Rating System	47
Table 3.2	: Initial Criteria List	51
Table 3.3	: Interview (A) Survey Results	57
Table 4.1	: Simo's Normalization Procedure.....	65
Table 4.2	: Simo's Clusters Weights Estimation.....	66
Table 4.3	: Simo's Criteria Global Weights Estimation.....	67
Table 4.4	: Categories Estimated Weights	67
Table 4.5	: Criteria Estimated Weights	68
Table 5.1	: Initial List of Sustainability Dimensions	74
Table 5.2	: Sustainability Dimensions Material Selection.....	75
Table 5.3	: Bridges Materials Sustainability Scores	81
Table 6.1	: Materials Quantities BaniMazar Bridge over the Nile	85
Table 6.2	: SOOMS Total cost Minimization Objective Values	92
Table 6.3	: SOOMS Sustainability Score Maximization Objective Values.....	93
Table 6.4	: MOOMS Terminology	94
Table 6.5	: MOOMS Category and Material Indices, Costs, and Scores	97
Table 6.6	: MOOMS Pareto Front Values	98

LIST OF FIGURES

Fig. No.	Title	Page
Fig. 1.1	: Proposed Research Methodology	7
Fig. 2.1	: Egyptian Energy Expenses Distribution (Egypt Expenses, 2010)	19
Fig. 2.2	: A Commercial Building Expenses over Service Life (USA)	20
Fig. 2.3	: Main Criteria of Green Performance	35
Fig. 2.4	: Illustration of Pareto front to Maximize multi objective Optimization Problem.	39
Fig. 2.5	: Illustration of Pareto front for a Minimize Multi Objective Optimization Problem	39
Fig. 3.1	: Estimated Mean Values of Importance Level for the Final List of Criteria.....	58
Fig. 3.2	: Estimated Mean Values Project Requirements Category.....	58
Fig. 3.3	: Estimated Mean Values for Environment and Water Category ...	59
Fig. 3.4	: Estimated Mean Values for Access and Equity Category	59
Fig. 3.5	: Estimated Mean Values for Construction Activities Category	60
Fig. 3.6	: Estimated Mean Values for Materials and Resources Category ..	60
Fig. 4.1	: Credit Distribution amongst Bridge Rating System Categories...	69
Fig. 4.2	: Proposed Bridges Rating System Classes	70
Fig. 6.1	: BaniMazar Bridge Axis Layout.....	86
Fig. 6.2	: BaniMazar Bridge over the Nile Sections Plan	87
Fig. 6.3	: BaniMazar Bridge Longitudinal Profile	88
Fig. 6.4	: Flow Chart Illustrates Pareto front generation using MATLAB Solver	96
Fig. 6.5	: MOOMS Pareto Front Optimal Solutions	99

NOMENCLATURE

AASHTO	American Association of State Highway and Transportation Officials
ACEC	American Council of Engineering Companies
ACPA	American Concrete Pavement Association
APWA	American Public Works Association
ASCE	American Society of Civil Engineers
BEST	Building Environmentally and Economically Sustainable Transportation
CARB	California Air Resources Board
DOT	Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GDP	Gross Domestic Product
GHP	Green Highways Partnership
GSHC	T&DI/ASCE 1 st Green Streets and Highways Conference

IDOT	Illinois Department of Transportation
I-LAST	Illinois Livable and Sustainable Transportation
IRTBA	Illinois Road and Transportation Builders Association
LCA	Life Cycle Assessment
LCCA	Life-Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
MTO	Ministry of Transportation (Canada)
OMR	Office of Materials and Research (specifically)
PI	Principal Investigator
ppm	parts per million (air pollution unit)
SIPRS	Sustainable Infrastructure Project Rating System
STEED	Sustainable Transportation Environmental Engineering and Design
SWMs	Solid Waste Materials
T&DI	Transportation and Development Institute
TRIS	Transportation Research Information Service

USGBC	Leadership in Energy and Environmental Design Reference Guide for New Building Construction
CH2M Hill	University of Washington
SESC	Soil Erosion and Sedimentation Control Measures
SWMP	Storm-water Management Plan
NPDES	National Pollutant Discharge Elimination System
MDEQ	Michigan Department of Environmental Quality
BMP's	Approved Best Management Practices
SCM	Supplemental Cementitious Materials
NCHRP	National Cooperative Highway Research Program

ABSTRACT

Sustainable development principles have been implemented in various sectors including construction. Proper development and operation of infrastructure projects, such as bridges and highways, can contribute significantly to the mission of sustainable development. In this respect, there is little existing work on appropriate methods to assess the sustainability performance of bridges projects. This thesis introduces a key-list of gathered important criteria that affect the sustainability of bridge projects. Various construction industry standards have been reviewed in order to decide the criteria that influence sustainability of bridges' projects. The initial list of criteria has been identified by unstructured interviews. Then, structured interviews surveys have been conducted to identify the final list that is deemed important in rating green bridges. Various construction industry standards have been reviewed to decide on the criteria that influence sustainability of bridges' projects. Final criteria results from this thesis are used to develop a green bridge rating system to achieve sustainable development. Degree of importance and weights of these criteria are determined using Simo's procedure. Five classes of bridges are proposed to judge their status with respect to sustainability, with these being Non-Green, Certified, Green, total Green, and Evergreen. Material selection has been identified as an area where designers and contractors can have a significant impact on the sustainable performance of a bridge. Objective criteria such as design considerations and cost constraints can play a role in the selection of materials. However, there may be subjective criteria that could also impact the selection of materials. As such, an optimization model is developed to help decision makers to select materials. The research proposes a conceptual instrument that measures the user-based assessment of material sustainability and validates decision-maker's perceptions in order to evaluate the contribution of characteristics in materials selection. Interviews surveys of design and construction experts in sustainability and green practitioners were carried out. The results of the survey reveal that attention should be paid when taking the decision of which material should be used. This decision bears significant environmental, economic, financial, and social influences. Selecting inappropriate materials can be expensive, but more importantly, it may preclude the achievement of the desired environmental goals. The contribution of this research is the development of a framework that consists of two modules for selecting appropriate building materials in order to help decision-makers with the appropriate