THE RELATIONSHIP BETWEEN NEW STRUCTURAL SYSTEMS, FORM GENERATION AND NEW BUILDING TECHNOLOGIES OF LARGE-SPAN BUILDINGS IN THE 21ST CENTURY

By

Omnia Mamdouh Hashim Shattoury

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ARCHITECTURAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

THE RELATIONSHIP BETWEEN NEW STRUCTURAL SYSTEMS, FORM GENERATION AND NEW BUILDING TECHNOLOGIES OF LARGE-SPAN BUILDINGS IN THE 21ST CENTURY

By

Omnia Mamdouh Hashim Shattoury

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ARCHITECTURAL ENGINEERING

Under the Supervision of

Prof. Dr. Sherine Wahba

Professor of Architecture
Architectural Engineering Department
Faculty of Engineering, Cairo University

Dr. Tarek Ibrahim Nasr

Lecturer of Architecture
Architectural Engineering Department
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

THE RELATIONSHIP BETWEEN NEW STRUCTURAL SYSTEMS, FORM GENERATION AND NEW BUILDING TECHNOLOGIES OF LARGE-SPAN BUILDINGS IN THE 21ST CENTURY

By
Omnia Mamdouh Hashim Shattoury

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
ARCHITECTURAL ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Sherine Mohy El-Din Wahba
_____
Prof. Dr. Emad Aly El-Din El-Sherbiny
_____
Prof. Dr. Sherif Sabry El-Attar
Professor of Architecture and Building Technology (Fayoum University)
_____

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

Engineer's Name: Omnia Mamdouh Hashim Shattoury
Date of Birth: 23/01/1991
Nationality: Egyptian
E-mail: omniamamdouh2011@yahoo.com
Phone: 002-01004963044
Address: Tiba Gardens (6 of October)
Registration Date: 01/10/2012
Awarding Date: 12/2016
Degree: Master of Science
Department: Architectural Engineering

Supervisors:

Prof. Dr. Sherine Mohy El-Din Wahba
Dr. Tarek Ibrahim Nasr El-Din

Examiners:

Prof. Dr. Sherine Mohy El-Din Wahba (Thesis main advisor)
Prof. Dr. Emad Aly El-Din El-Sherbiny (Internal examiner)
Prof. Dr. Sherif Sabry El-Attar (External examiner)
Professor of Architecture and Building Technology (Fayoum University)

Title of Thesis:

THE RELATIONSHIP BETWEEN NEW STRUCTURAL SYSTEMS, FORM GENERATION AND NEW BUILDING TECHNOLOGIES OF LARGE-SPAN BUILDINGS IN THE 21ST CENTURY

Key Words:
Large Spans, Structural Systems, Form Generation, Complex Forms, New Building Technologies

Summary:

This research studies the relationship between new structural systems and architectural forms in large span buildings specially after using digital technology tools in the 21st century. It studies the impact of form on structure and vice versa. Large span structural forms represent a great challenge in the field of structure as in the field of architecture. This is due to their need to overcome the forces and loads. The forms of the 21st century are considered to be complex. Digital technology is an innovative tool for derivation and transformation of architectural form (form generation in the 21st century). So form and structure has to work together in order to give at the end an innovative and iconic buildings.

Acknowledgments

First of all, my thanks and gratitude are to GOD for giving the human beings a drop of his infinite ocean of knowledge.

I wish to express my great appreciation and thanks to Dr. Sherine Mohy El Din Wahba, Professor, Architectural Engineering Department, Faculty of Engineering, Cairo University, for her kind guidance and valuable advice.

I also wish to express my deep indebtedness to Dr. Tarek Ibrahim Nasr El Din, Architectural Engineering Department, Faculty of Engineering, Cairo University, for his generous guidance and encouraging, sincere help, consistent support by all means and asking, valuable suggestions, and precise advice through all stages of this research work.

Dedication

To my mother Prof. Hanan Siam, to whom, I owe too much, who supported, encouraged, and stand for me. To my father Dr. Mamdouh Hashim, my backbone, who supported me throughout my life. To my husband Ramy Badawy, who encouraged and supported me so much. My brother Ahmed and his wife Engy who supported me to accomplish my thesis.

Table of Contents

ACKNOWLEDGMENTS I
DEDICATION III
ABSTRACT XXI
CHAPTER 1 : RESEARCH FRAMEWORK 1
1.1. INTRODUCTION 1
1.2. RESEARCH PROBLEM 2
1.3. RESEARCH QUESTIONS 2
1.4. RESEARCH OBJECTIVES 2
1.4.1. Main Objective 2
1.4.2. Sub-Objectives 3
1.5. RESEARCH HYPOTHESIS 3
1.6. RESEARCH METHODOLOGY 4
1.7. RESEARCH STRUCTURE 6

CHAPTER 2 : BRIEF HISTORY OF LARGE SPAN STRUCTURES 11
2.1. INTRODUCTION 11
2.2. DEFINITIONS 12
2.2.1. Large Span Structures 12
2.2.2. Mega Structures 13
2.3. BRIEF HISTORY OF LARGE SPAN STRUCTURES 13
2.3.1. The Pre-industrial age 13
2.3.1.1. Building Typology 13
2.3.1.2. Building Materials 14
2.3.1.3. Construction Techniques 15
2.3.1.4. Structural Systems 16
2.3.1.5. Form 16
2.3.2. The 18th Century (The Industrial Revolution) 17
2.3.2.1. New Inventions 17
2.3.2.2. Building Materials 18
2.3.2.3. Construction Techniques 18
2.3.2.4. Structural systems 18
2.3.2.5. Form 19
2.3.3. The 19th Century (New Structures and Architecture) 19
2.3.3.1. New Functions 19
2.3.3.2. Building Materials 20
2.3.3.3. Construction Techniques 22
2.3.3.4. New Structural Systems 23
2.3.3.5. Form 25
2.3.4. The 20th Century 26
2.3.4.1. New Functions 26
2.3.4.2. Building Materials 26
2.3.4.3. Construction Techniques 29
2.3.4.4. New Structural Systems 31
2.3.4.5. Forms 35
2.4. CONCLUSION 36

CHAPTER 3: STRUCTURAL SYSTEM CLASSIFICATION OF LARGE SPAN BUILDING 41

3.1. INTRODUCTION 41
A- LINEAR STRUCTURES: 47
3.2. PRIMARY COMPRESSION 47
3.2.1. Post and Beam Structure: 47
3.2.2. Framed Construction 47
3.2.2.1. Linear frames 49
3.2.2.2. Polygonal frames 49
3.2.2.3. Curvilinear frames 50
3.2.3. Vaults 50
3.2.3.1. Barrel vault 50
3.2.3.2. Groin Vault: 51
3.2.3.3. Gothic Vault: 51
3.2.3.4. Lamella Vault: 51
3.2.4. Trusses 52
3.2.4.1. Planer Trusses (2D) 53
3.2.4.2. Prismatic Trusses (3D) 54
3.2.4.3. Space Frames: 55
3.2.5. Domes: 57
3.2.5.1. Two Dimensional Domes: 57
3.2.5.2. Three Dimensional Domes: 57
3.3. PRIMARY TENSION STRUCTURES 59
3.3.1. Cables 59
3.3.2. Cable roofs 59
B- SURFACE-RESISTANT STRUCTURAL FORMS 61
3.4. PRIMARY COMPRESSION STRUCTURES 61
3.4.1. Planer structures 61
3.4.1.1. Flat slabs 62
3.4.1.2. Folded Plates 62
3.4.2. shells 63
3.4.2.1. Single Curvature Shells: 64
3.4.2.2. Double Curvature Shells: 65
3.5. PRIMARY TENSION STRUCTURES 69
3.5.1. Tensile: 69
3.5.2. Pneumatic Structure: 71
3.5.2.1. Air Inflated Structures: 71
3.5.2.2. Air Stabilized Structures: 72
3.5.2.3. Structures lifted by light gases 72
3.6. COMBINED STRUCTURES (SOME FURTHER SIGNIFICANT STRUCTURES AND ASSEMBLIES) 73
3.6.1. Hybrids 73
3.6.2. Tensegrity Structures 74
3.6.3. Other Examples of Combined Structures 74
3.7. CONCLUSION 75

CHAPTER 4 THE APPLICATION OF DIGITAL TECHNOLOGY TOOLS ON ARCHITECTURAL AND STRUCTURAL FORMS IN THE 21ST CENTURY.. 83

4.1. INTRODUCTION AND DEFINITIONS 83
4.1.1. Technology 83
4.1.2. Digital 84
4.1.3. Digital Revolution 85
4.2. DIGITAL TECHNOLOGY TOOLS 85
4.2.1. Software Types 85
4.2.2. Classification of Digital Design Tools 86

4.2.3. Types of Digital Form Generation Design Tools 86
4.2.4. Generative Design-Tools 87
4.2.4.1. Structural Generative Design-Tools 87
4.2.4.2. Concept Development and Sketching Tools 88
4.2.5. Computer Applications and New Techniques 89
4.2.5.1. Virtual Reality 91
4.2.5.2. Animation 93
4.2.5.3. New Techniques: 94
4.3. DIGITAL TECHNOLOGY TOOLS AND COMPUTER PROGRAMS VS ARCHITECTURAL FORM 94
4.3.1. Digital Architecture 94
4.3.2. Different factors are affecting directly on the architectural design concepts in the age of digitalization 95
4.3.3. How Digital Architecture Became an International Trend? 95
4.3.4. Digital Technologies and Building's Form 95
4.3.5. Levels of design computability: 96
4.4. DIGITAL TECHNOLOGY TOOLS VS STRUCTURAL FORM 97
4.4.1. Structural System in Construction Process 98
4.4.2. Design Aids and Structural Form 99
4.4.3. The Influence of the Technological Development on New Structural System 99
4.5. NEW ARCHITECTURAL APPROACHES BASED ON INFORMATION TECHNOLOGY 100
4.5.1. Emergent Architecture 100
4.5.2. Liquid Architecture 100
4.5.3. Hyper Surfaces Architecture 101
4.5.4. Genetics Architecture 102
4.5.5. 3D Hologram Virtual Architecture 102
4.5.6. Xefirotarch Architecture 103
4.5.7. Hybrid Architecture 103
4.5.8. Meta-Architecture 104
4.5.9. Brutalism Architecture 104
4.5.10. Blobitecture 105
4.5.11. Amid Architecture 105
4.5.12. Qua Virarch Architecture 106
4.5.13. Exodesic Architecture (Dennis Dollens) 106
4.5.14. Multimedia Architecture 107
4.6. CONCLUSION 108

CHAPTER 5 FORM GENERATION IN THE 21ST CENTURY 113

5.1. INTRODUCTION 113
5.2. THE DIFFERENCE BETWEEN SHAPE AND FORM 113
5.3. DETERMINATES OF FORM 114
5.3.1. The context 115
5.3.2. Building function 115
5.3.3. Particular region 115
5.3.4. Building material 115
5.3.5. Psychological aspects 115
5.3.6. The spirit of the age 116
5.4. FORM GENERATION APPROACHES (FORM IMPROVING AND FORM FINDING) 116
5.5. TYPES OF FORM 117
5.5.1. Geometrical Forms 117
5.5.1.1. Types of Geometrical Forms: 117
5.5.1.2. The ways to use geometry in generating building's form: 119
5.5.1.3. Geometry in architectural and structural design: 119
5.5.1.4. Geometry of Structural Form: 120
5.5.2. Composite Forms (Principles of compositions) 121