GRADUATION PLAN

MASTER OF SCIENCE ARCHITECTURE, URBANISM & BUILDING SCIENCES

PERSONAL INFORMATION

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STUDIO

Studio: Building Technology

Mentors: Andrew Borgart (Structural Design) and Pirouz Norian (Computational Design)

Argument of choice of the studio: To achieve the advanced combination of architectural, structural and computational design.

GRADUATION PROJECT

Title: TENSEGRITY STRUCTURE FOR LARGE SPAN ROOF (for Feyenoord Stadium)

Location: Feyenoord, Rotterdam, the Netherlands.

Keywords: Tensegrity, Slenderness, Transparency, Stadium Architecture, Computational Workflow, Material Optimization, Structural Optimization.

Background:

If the architect’s enthusiasm for the design, composed in terms of form and space, could be linked successfully to the engineer’s enthusiasm for the structure, they might produce buildings that would cause us to rethink the way in which we build (A. Flury, 2012). The art of structural engineering becomes architecture is something that proves the great cooperation between the architect and the engineer. And mega-structure is where the technological innovation of structure comes to architecture. Forms, forces, and functions play important roles in this partnership.
For more than 50 years, tensegrity is considered an innovative structural concept and it has the potentials to become a super-efficient structural system. In this system, the coupling between forces and forms is very tight, and this relation is actually made visible by structural components themselves. The very specific type of structural composition surprises and fascinates everyone for seeing them at the first time: struts seem to float on the air (R. Motro, 2012). And this is also the key point since people, engineers and architects more than the others, are surprised by this new kind of flow of forces. They are used to gravity effect, and in this case, gravity seems to be absent.

Regardless its potentials, there has not been much application of tensegrity principle in the construction field. Examples have remained at the prototype state for lack of adequate technological design studies. By studying the complexity of tensegrity and applying it to a football stadium roof, this thesis would be dedicated to exploring a design method which would help to realize this structural composition in architectural practice.

**Problem Statement:**

The problem of form-finding is central in the study of tensegrity system. The primary obstacles to the practical application of tensegrity, which are mentioned in "A Practical Guide to Tensegrity Design" (R.W. Burkhardt, 2008), are:

1. Strut congestion - as some designs become larger and the arc length of a strut decreases, the struts start running into each other.
2. Poor load respond - “relatively high deflections and low material efficiency, as compared with conventional, geometrically rigid structures.”
3. Fabrication complexity - spherical and domical structures are complex which can lead to difficulties in fabrication.
4. Inadequate design tools - lack of design and analysis techniques for these structures has been a hindrance.

**Objective:**

**Main Objective:**

**The purpose of the thesis is to understand the complexity of tensegrity structure and be able to apply it in architectural practice with the help of computational tools.**

**Sub-objectives:**

- Design a mega-structure which would be in a form of a stadium roof.
- Use computational tools to solve complex problem of tensegrity structure.
- Minimize the use of materials, increase structural slenderness and transparency of structure.
- Explore the construction methods and technique to realize such a large span tensegrity structures.

Research Questions

Main question:
How to design a constructible tensegrity structure for a large span roof of a stadium?

Sub-questions:
What is the software workflow that would help in designing tensegrity structure?
What is the tessellation of tensegrity that should be investigated?
What is the structural morphology of tensegrity systems?
What is the topology of tensegrity systems?
What are the structural principles that can be applied to analyze tensegrity systems?
What is the method to translate mathematical principles of tensegrity to digital tools?
What is the role of physical modeling in tensegrity study?
How to visualize mechanic behaviors of tensegrity systems?
How can designers optimize the geometrical form, the material efficiency, and the cross section of structural components in tensegrity systems?

PROCESS

Methodology

The research would be started with literature studies related to tensegrity systems, rigidity theory, and large-span structures. Researches in areas of form-finding, pattern, tessellation, morphology, and topology of the structure systems would be further investigated. Along with literature review, modeling techniques will be conducted digitally and computationally to acquire more understanding about parametric design as well as the structural composition of tensegrity systems.

After that, a generic design method will be introduced to construct a large-span dome (160x210m) with a huge central opening. The technique would be transformed into the design of a new tensegrity roof for Feyenoord stadium in Rotterdam, the Netherlands. Based on this particular case, there would be practical inputs and requirements for the performance of the structural model and optimization in terms of cross-sectional properties, material efficiency, geometrical rigidity, contextual response, stability, and constructability.

Finally, a fabrication method and technique will be produced according to the structural model in a way that it would help the model to perform better
structurally and aesthetically. For the constructability, important details would be developed to help the construction process of the tensegrity structure in large scale.

- Brief Design Approach

- Programs in use

- Comprehensive Approach
Boundary Conditions:

Starting point: Literature review with the typology, morphology, pattern of tensegrity systems, and stadium morphology in general.

How: A digital tool would be developed in the process to help design and analyze structural systems of a tensegrity roof. Then this generic tool would be applied to a particular case which is Feyenoord Stadium in Rotterdam. Based on this example, the construction and fabrication method would be introduced.

Who: the cooperation between the architect and the engineer.
What: Form-finding method, parametric modeling method, physical modeling method, structural principles, a workflow of software (modeling software to FEM software), mechanic behaviors, construction and fabrication, stadium (210x160m, 60,000 seats).

Where: Rotterdam, the Netherlands.

When: The research would take place from the birth of tensegrity to its present achievement toward the future of the structural systems.

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- V. G. Jauregui, Tensegrity Structures and Their Application to Architecture, School of Architecture, Queen’s University Belfast.


- D.M. Smidt, Freeform Follows Functions, TU Delft, Faculty of Architecture and Built Environment, 2014.

**RELEVANCE**

On the scientific aspect, this thesis would contribute to constructing to the young library of tensegrity structure with a design method for application in large-scale construction. It would help to resolve the obstacles posed by the complexity of such the system by the innovative use of computational tools. In addition, a way of improving the rigidity and usability of tensegrity in mega-structure would be explored, which paves a way to realize the construction and fabrication of the buildings using this structural system.

The collaboration between the architect and the engineer would be developed along with the process of this graduation project. The workflow proposed by this thesis could lead to a better communication between different disciplines working around a common parametric platform.

On the social aspect, a new way of tensegrity application can reflect the technological innovation of our time in a complex type of building covering a huge open space, a stadium. A stadium is a major component in social interaction in culture around the world. It is currently the place where people are able to come together to celebrate sport, enjoy a concert, or
congregate for self-expression, or some other similar social events. Society would obviously benefit from the huge impact of using this intriguing structure for the redevelopment of a current urban context.

**ORGANIZATION AND TIME-PLANNING**

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