TENSEGRITY STRUCTURE: THE DESIGN DEVELOPMENT OF TENSEGRITY STRUCTURE FOR FURNITURE DESIGN

By

MR. Visuwat MALAI

A Thesis Submitted in Partial Fulfillment of the Requirements for Doctor of Philosophy DESIGN ARTS (INTERNATIONAL PROGRAM)

Silpakorn University

Academic Year 2023

โครงสร้างแรงดึงสมบูรณ์: การพัฒนาการออกแบบโครงสร้างแรงดึงสมบูรณ์สำหรับการออกแบบเฟอร์นิเจอร์

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By	MR. Visuwat MALAI
Field of Study	DESIGN ARTS (INTERNATIONAL PROGRAM)
Advisor	Professor Dr. Eakachat Joneurairatana
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Faculty of Decorative Arts, Silpakorn University in Partial Fulfillment of the Requirements for the Doctor of Philosophy

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640430009 : Major DESIGN ARTS (INTERNATIONAL PROGRAM)

Keyword : Tensegrity, Structure, Tension, Compression, Furniture

MR. Visuwat MALAI : TENSEGRITY STRUCTURE: THE DESIGN DEVELOPMENT OF TENSEGRITY STRUCTURE FOR FURNITURE DESIGN Thesis advisor : Professor Dr. Eakachat Joneurairatana

The origins of Tensegrity structures were discovered more than seventy years ago and are widely employed in engineering and architecture for the construction of bridges, domes, and buildings. However, these structures necessitate thorough classification, development, and application. The primary objective of this research is to scrutinize innovative concepts and propose design advancements grounded in the prevalent use of tensegrity structures in architecture and engineering. The specific research objectives are delineated as follows: 1) Investigate the historical evolution of Tensegrity structures, 2) Classify structures based on their properties, facilitating their appropriate application in design, and 3) Develop products derived from the Tensegrity framework with the potential for broad applicability across various contexts, including furniture and home decorations.

The fundamental principle guiding the operation and characteristics of Tensegrity structures is the emphasis on focused tensile forces, utilizing solely two forces - compression and tension - to amalgamate the entire structure, ensuring its independent formation and stability. Networked tensile forces can generate internal compressive forces within the carrier structure, with compressed members typically not interconnecting or in contact. These structures exhibit robust, lightweight, flexible, and adaptable characteristics, rendering them suitable for a diverse range of design applications. Consequently, they manifest the potential to be developed for various purposes and are well-suited for different types of structures.

This qualitative experimental research initiative systematically explores the integration of Tensegrity structures into various design domains. The six-part research methodology includes an exhaustive examination of existing knowledge. Part 1, Exploration of Tensegrity Structure. Part 2 Classified according to properties for

discerning advantages and disadvantages. Part 3, Data Collection and Synthesis, actualization of the design concept through data synthesis for discerning advantages and disadvantages, collection and synthesis of pertinent information. Part 4, Design Development. Part 5, Formulation of experiment hypothesis. Part 6 is exclusively dedicated to presenting innovative design concepts inspired by Tensegrity structures, showcasing diverse designs and artistic products pivotal for their continued utilization and development.

The research results found that Tensegrity structures possess the potential and capability for further development across a variety of design expressions. This study furnishes comprehensive foundational knowledge regarding the Tensegrity structure. Encompassing definitions, classifications, properties, and applications, Tensegrity serves as an essential foundational database and knowledge repository crucial for applications, advancements, and design optimization.

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First and foremost, I would like to express my deepest gratitude to Professor Dr. Eakachat Jonesairatana, my advisor, who provided guidance and expertise instrumental in shaping the direction of this study. The invaluable insights gained from his mentoring greatly enhanced the quality and depth of the research. I would also like to thank Assistant Professor Dr. Veerawat Sirivesmas, my second advisor, for his advice and encouragement.

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Visuwat MALAI

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Chapter 1

Introduction

1.1 Background and Significance of the Research

Tensegrity, a structural system has been under development for about seventy years. The origin of Tensegrity structures is still being clarified by the inventor. Tensegrity structures have inspired significant works of art and architecture known for their lightweight construction and large spans. The structures are driven by a growing interest in smart design, capable of adjustable and controlled shapes (Tibert and Pellegrino 2011). The term Tensegrity (Jáuregui 2020) refers to the integrity of a structure realized through a combination of tension and compression forces. It is also defined as a prestressed pin-jointed truss featuring struts under compression and cable members enduring tension (Song, Scarpa, and Schenk 2022). The methodical arrangement of tensile (strings) and compressive members (bars), leads to the creation of stable structures (Goyal et al. 2019). This structural paradigm remains relevant due to the complexity and limited understanding of the functional principles of structures. For this reason, tensegrity structures can be found in many works covering a broad spectrum. This type of structure is lightweight and flexible, so the system that connects the individual parts within the structural elements is complex and the assembly process is cumbersome. For this reason, this type of structure is exceedingly rare. It therefore lacks distribution and further development. Originally, there were only two forms of Tensegrity structures. The first is a dome-shaped type that can cover or enclose an area in a circular shape. The second type is a line type that cannot be covered spatially.

The objective of this research is to contribute to the development and promotion of structures in architecture, engineering, industrial design and other creative fields. The outcomes of this research have yielded innovative designs and driven the development of novel concepts associated with Tensegrity. These designs hold potential applications in various fields, including architecture, engineering and art. Furthermore, the research has led to artistic expressions, signifying that the Tensegrity concepts investigated have been translated into creative and visually appealing forms. This manifestation implies a potential contribution to the convergence of science, engineering and art.

1.2 Statement of the problem

1.2.1 The classification of Tensegrity structures according to their properties is essential to facilitate their appropriate use in different applications.

1.2.2 The Tensegrity structure has intriguing and distinctive features, and its advantages provide a foundation for further development of design efforts.

1.2.3 The fabrication and installation process present a major challenge as most skilled workers are not familiar with the stresses associated with the structure.

1.3 Hypothesis

1.3.1 The study of the origins, types and classifications based on the properties of Tensegrity structures can serve as a knowledge base for the selection of structures suitable for the intended use and for the design of a new type of Tensegrity structure.

1.3.2 The study of Tensegrity structures can contribute to the development of new concepts and the production of contemporary furniture design.

1.4 Objective of the Research

1.4.1 To study and investigate the historical evolution and development of Tensegrity structures, focusing on individuals closely Tensegrity in architecture, and identify principles and definitions of the structure.

1.4.2 To categorize structures based on their properties to facilitate appropriate application in design and create, develop and design new types of Tensegrity structures.

1.4.3 To introduce Tensegrity structures into art and design by promoting a deeper understanding of the interplay between Tensegrity Structure principles and application concepts in functional and esthetic design in furniture design.

1.5 Scope of Research

1.5.1 To study the history of Tensegrity Structures, including definitions of Tensegrity Structures and design concepts.

1.5.2 To classify and analyze the properties of each Tensegrity structure to be used as a basis for design.

1.5.3 To develop and conduct experimental tests for the construction of Tensegrity to achieve comprehensive coverage and large span.

1.5.4 Formulate furniture designs that apply the principles of Tensegrity Structures integrating esthetic and functional concepts.

1.6 Research Framework

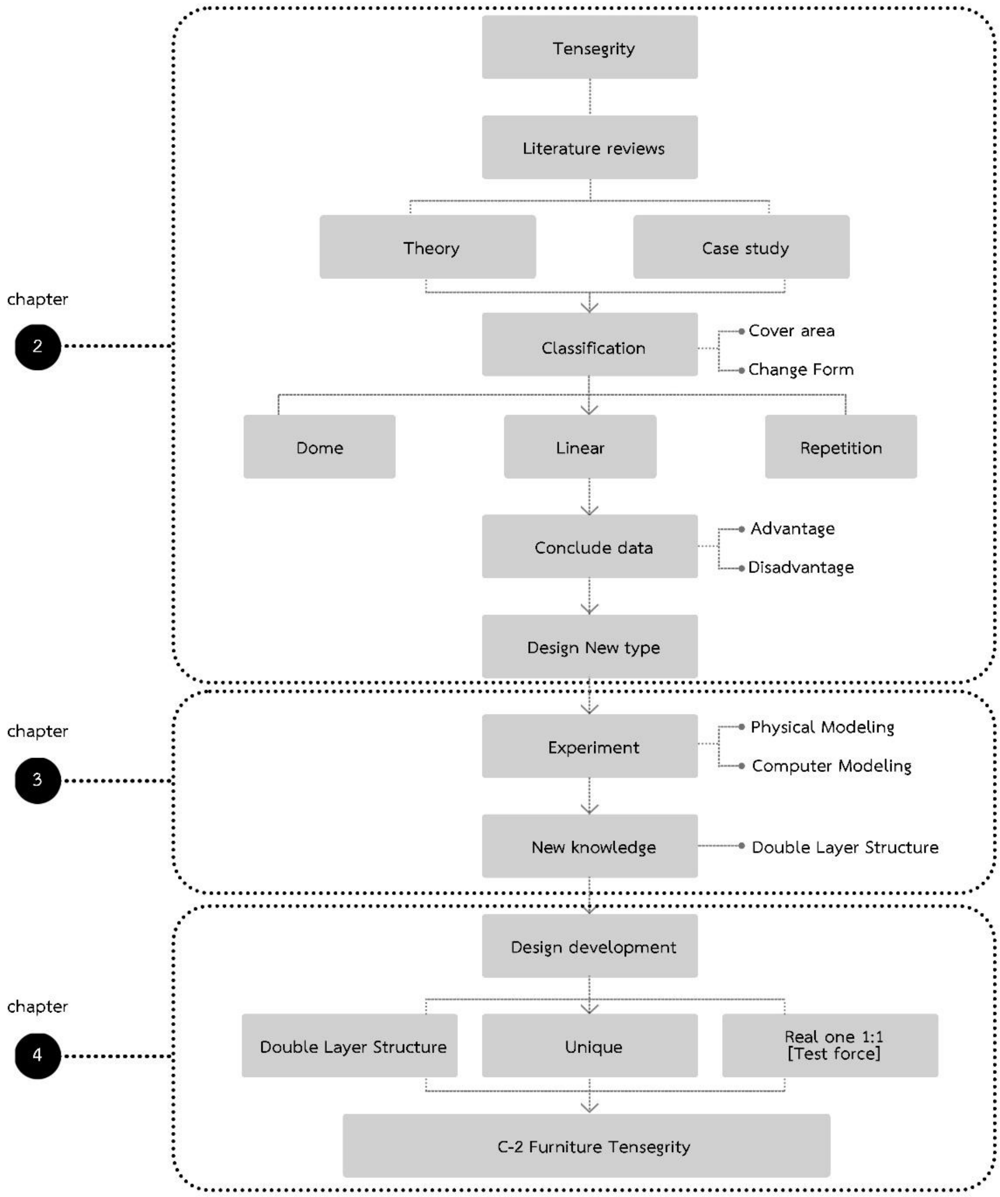


Figure 1 Research Framework

1.7 Research methodology / Process

This qualitative, experimental research initiative systematically explores the integration of tensegrity structures in different design domains, using methods such as observation and experimentation. The main goal is to promote tensegrity structures in fields such as architecture, engineering, industrial design and other creative disciplines. Inspired by structural principles observed in bone structure, the muscular system and human movement, the study seeks to merge these concepts with structural tensegrity principles.

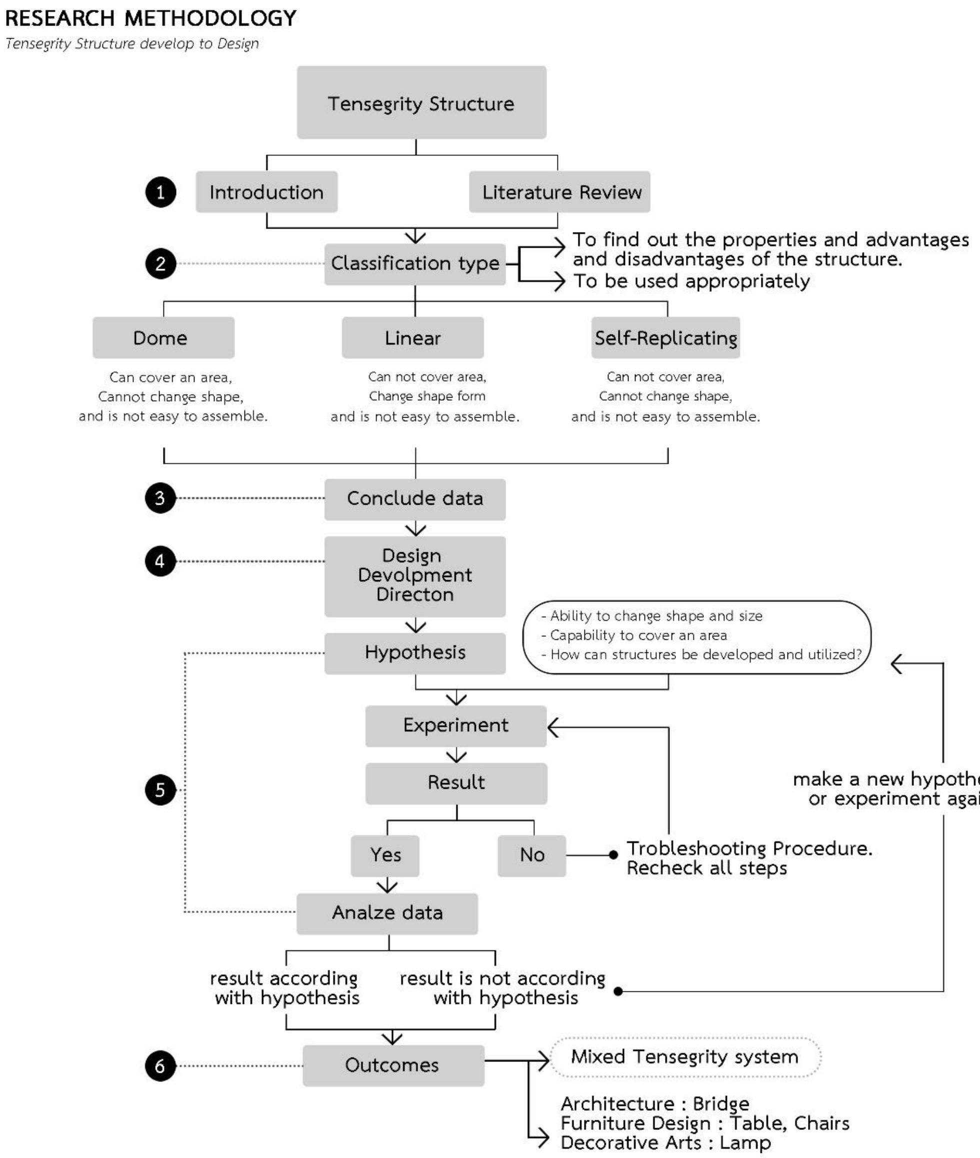


Figure 2 Design Research Process

The study's data, derived from the application of structural principles to furniture design, will be subjected to rigorous real-world scrutiny to uncover new challenges and identify key issues in practical application. Research methods include exploring the origin and definition of structures, classification based on properties, collecting and synthesizing data, developing designs, and formulating experimental hypotheses. Furthermore, the study introduces concepts derived from the application of tensegrity structures. It provides a theoretical foundation for the designs and links them to biological and structural principles. The research contributes significantly to the advancement of tensegrity structures by applying it to new concepts, including furniture design, and developing various designs inspired by tensegrity structures.

1.8 Limitation of the Research

This research aims to present a method for the connection, assembly and Tensegrity structural parts that can be expanded both in width and length, and to design architectural designs from this system structure to have an assembly method that does not require installation. It is too complex that the research data focuses on the representation of methods or practices rather than numerical representations. This research may have experimental limitations in terms of the materials used in the design and the tools used in the experiments, including the budget for experimentation and production.

1.9 Research Outcome

1.9.1 To understanding the fundamental principles of structures that involves grasping the core concepts and underlying principles that govern stability, behavior, and design.

1.9.2 Knowledge of the fundamental principles of structures enables classification and appropriate application for use.

1.9.3 The acquisition of the knowledge to create and develop Tensegrity structures to facilitate the creation of a variety of designs in the art and design industry.

1.9.4 The application of Tensegrity structures extends to functional and esthetic works, such as product design, furniture and home decorations.

1.10 Definition of Terms

1.10.1 Tensegrity is a structural concept that relies on the balance of tension and compression elements to create stable and self-supporting structures.

1.10.2 Structure means a framework or arrangement of elements designed to support or enclose something and to provide stability, organization or a particular form or function

1.10.3 Form-finding means the process of determining the optimal shape or configuration of a structure or object based on factors such as material properties, loads and desired performance characteristics.

1.11 The relationship between research objective (RO), research question (RQ), research methodology (RM), research outcome (ROC)

Table 1 the relationship between RO, RQ, RM, and ROC

	FRAMEWORKS OF TITLE	SUBJECT OF THE RESEARCH	TENSEGRITY STRUCTURE
		SETTING:	DESIGN DEVELOPMENT
		VARIABLE OF THE RESEARCH	FURNITURE DESIGN
	TITLE	TENSEGRITY STRUCTURE: THE DESIGN DEVELOPMENT OF TENSEGRITY STRUCTURE FOR FURNITURE DESIGN	
PROBLEM STATEMENTS	1. The classification of Tensegrity structures according to their properties is imperative to facilitate their appropriate use in different applications.	2. The Tensegrity structure has intriguing and distinctive features, and its advantages provide a foundation for further development of design endeavors.	3. The fabrication and installation process present a major challenge as most skilled workers are not familiar with the stresses associated with the structure.
RESEARCH OBJECTIVES	1. To study and investigate the historical evolution and development of Tensegrity structures, focusing on individuals closely Tensegrity in architecture, and to find principles and definitions of the structure.	2. To categorize structures based on their properties to facilitate the appropriate application in design and to create, develop and design new types of Tensegrity structures.	3. To introduce Tensegrity structures into art and design by promoting a deeper understanding of the interplay between Tensegrity Structure principles and application concepts in functional and esthetic design in furniture design.
HYPOTHESIS	- What are current data Tensegrity structures and what is the definition of Tensegrity?	- What are the different types of structures and what are their respective features, advantages and disadvantages?	- How is the structure applied to gain greater recognition and usability in other design circles?

<table>
<tr><td>HYPOTHESIS</td><td colspan="2">The study of the origins, types and classifications based on the properties of Tensegrity structures can serve as a knowledge base for the selection of structures suitable for the intended use and for the design of a new type of Tensegrity structure.</td><td>- The study of Tensegrity structures can contribute to the development of new concepts and the production of contemporary furniture design.</td></tr>
<tr><td>RESEARCH METHODOLOGY</td><td>- Introduction
- Literature Reviews
- Data Analysis
- Qualitative Research
- Fieldworks
- Data Summary and review of the data</td><td>- Qualitative Research
- Fieldworks
- Experiment
- Design Process
- Computer Simulation</td><td>- Computer Simulation
- Experimental
- Design Process
- Production</td></tr>
<tr><td>RESEARCH OUTCOME</td><td>1. To understand the fundamental principles of structures, you need to grasp the core concepts and underlying principles that determine stability, behavior and design.

2. Knowledge of the fundamental principles of structures enables classification and appropriate application for use.</td><td>3. Acquiring the knowledge to create and Tensegrity structures facilitates the creation of a variety of designs in the art and design industry.</td><td>4. The application of Tensegrity structures extends to functional and esthetic works, such as product design, furniture and home decorations</td></tr>
</table>

Chapter 2

Literature Review

This research is centered on Tensegrity Structures, focusing on the historical background and origins associated with two pivotal figures, Kenneth Snelson and Buckminster Fuller. Additionally, it gathers detailed information regarding the theory and principles underpinning Tensegrity. The literature review is systematically divided into six parts as follows:

2.1 History and Background

2.1.1 Kenneth Snelson

2.1.2 Buckminster Fuller

2.2 Theory

2.2.1 Definition of Tensegrity Structure

2.2.2 Basic Principles

2.2.3 General Qualification

2.2.3.1 Advantages

2.2.3.1 Disadvantages

2.3 Case Studies

2.5.1 Compressive and tensile strength

2.5.2 Suspended roofs and tensile structures

2.5.3 Furniture

2.4 Summary

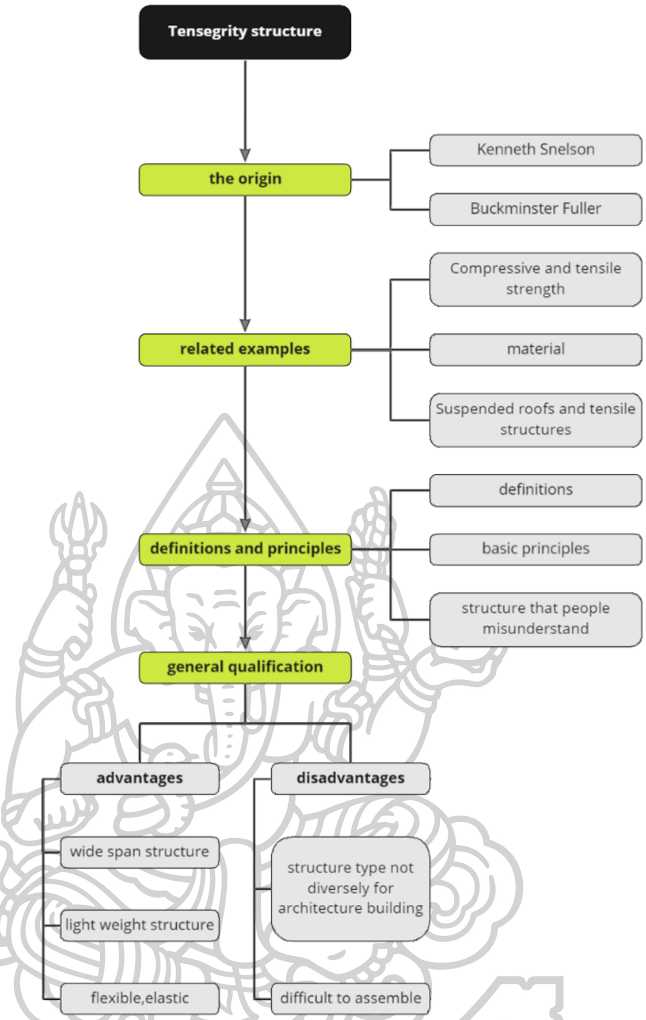


Figure 3 Research Theories and Literature Review Process Flowchart

2.1 History and Background

Tensegrity is a structural system that has been under development for about seventy years and has produced remarkable works of art and architecture characterized by lightweight construction and large spans. The shape and overall design of the structure can be determined. This structural paradigm remains relevant due to the complexity and limited understanding of the operational principles of structures. The origin of Tensegrity structures is still being determined via the inventor. These efforts also aimed to find a meaningful definition of the basic concept Tensegrity. Tensegrity structures have many applications, specifically in structural engineering, such as domes, bridges, and towers (Bansod, Nandanwar, and Burša 2014). In this study, different types of Tensegrity structures are classified, their composition is explained and the advantages and disadvantages of each variant are presented. In addition to the classification and properties, guidelines were also given for the development and promotion of the application of these structures in architecture, engineering, industrial design and other creative fields.

The origin of Tensegrity structures is still the subject of debate among inventors. Therefore, the aim of this study was to examine certain aspects and arguments that contribute to a deeper understanding of the structures and their origin, and highlight the intentions of the inventors. The narrative began with two closely related men, namely Richard Buckminster Fuller and Kenneth D. Snelson, who both claimed to be the inventors of Tensegrity. This first and most controversial point of the inventor was emphasized by a personal conflict that spanned three decades.

In the summer of 1948, Richard Buckminster Fuller took on the role of newly appointed professor at Black Mountain College (North Carolina, USA). This phase marked another facet of Richard's career, encompassing roles such as architect, engineer, mathematician, cosmologist, poet and inventor. Simultaneously, art student Kenneth Snelson enrolled in the geometric modeling class taught by Buckminster Fuller. Following the transformative summer and inspired by mentors like Buckminster Fuller, Kenneth Snelson began 3D modeling. Meanwhile, Fuller set about creating various sculptures and managed to create new lines, the groundbreaking Tensegrity structures. When he presented the sculpture to Buckminster Fuller and asked for an evaluation, it turned out that this creation contained the solution Fuller had been looking for years before he met Snelson. Fuller had worked extensively on the various concepts of Tensegrity, including nomenclature and the evolution of geometry using multidimensional vector systems and 3D. Despite these efforts, Fuller encountered challenges in combining the elements into a tangible model.

Buckminster Fuller began to refer to himself as the discoverer of the structures, although he recognized Kenneth Snelson as the original inventor. This change in perspective resulted from Fuller's introduction of the term "Tensegrity" in 1955, an abbreviation that stands for tensional-integrity or pull-based integration, which was not explicitly intended for this type of structure. Linking these structures with the invented term therefore fostered the misconception that Fuller was the sole inventor.

In late 1949, Fuller declared that a lasting legacy awaited Snelson. Over the years, however, this perspective changed, prompting Snelson to advocate for public recognition during the Fuller-curated exhibition at the MOMA Museum of Contemporary Art in New York in 1959. This also raised awareness of Snelson's aspirations. A few years later, Fuller again recognized Snelson for his amazing idea that played a crucial role in the discovery of these types of structures. This recognition was probably documented in Fuller's "Sailor's Book" However, it is worth noting that Snelson has often been portrayed as the catalyst for the discovery of Tensegrity structures. Despite earlier indications that Snelson would be mentioned in the book "Synergetics", this did not happen.

Tensegrity structures by these two people continued into the 1980s. Buckminster Fuller wrote a letter in response to a question from Kenneth Snelson, offering insights that would shed light on the attribution of structural invention. Despite Fuller's original conception of Tensegrity and the patented idea of the work, it had not been realized as an actual construction.

2.1.1 Kenneth Snelson

Kenneth Snelson was an accomplished sculptor who continues to play an important role Tensegrity to this day. Guided by the fundamental concepts of Tensegrity, Snelson collected and summarized information on structural engineering on a dedicated website, but remained committed to the field of sculpture and esthetics. The integration of in-depth physical and mathematical methods was also avoided due to the artistic background and comments on the difficulty of applying principles to Tensegrity structures that are not mathematical or geometric. This method remarkably encouraged the development of heterogeneous and asymmetrical structures that eventually led to sculptures celebrated on a global scale.

The Tensegrity system required detailed techniques approved by Kenneth Snelson, a fundamental process resulting in a synthesis of science and art.

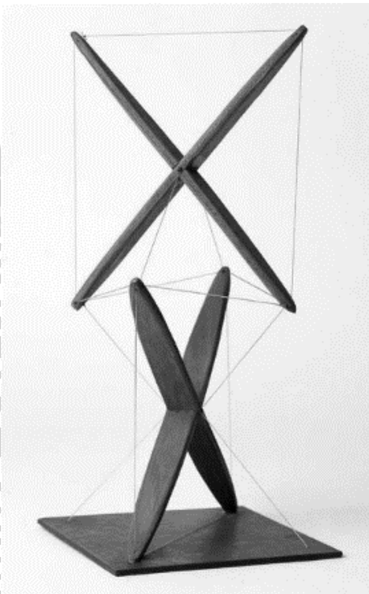


Figure 3 the "X-piece" Tensegrity Model

Source: Kenneth Snelson, 1948

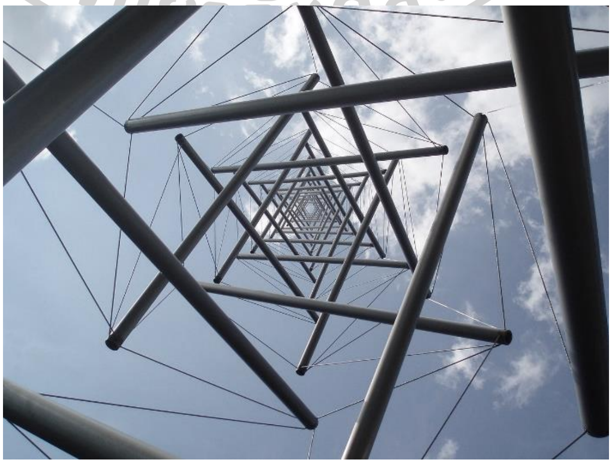


Figure 4 Kenneth Snelson Needle Tower

Source: Kenneth Snelson, 1969

The basic structural members of tensegrity were found to include compression and tensile elements allowing the formation and maintenance of a solid shape. Tensegrity structures comprise a unique design concept characterized by a combination of discontinuous compression elements (struts) within a continuous tensile network (cables or tendons) (Fraddosio, Pavone, and Piccioni 2019). The process ensures that the parts under compression are not adjacent or touching each other. Kenneth Snelson had experience with compression and tension elements as indicated in Figures 3 and 4 and several other relevant work. This model was considered to be a simple straight pipe joint and was called Tensegrity Linear Systems. Moreover, building a Tensegrity system requires detailed techniques that Kenneth Snelson has improved. The basic process that Kenneth Snelson develops in his work is a science and an art in itself.

Figure 5 Skylon Tower at Festival of Britain, 1951

Source: British Official Photograph,

(https://upload.wikimedia.org/wikipedia/commons/0/0b/In16695.jpg)

2.1.2 Buckminster Fuller

Buckminster Fuller pursued a different method compared to Kenneth Snelson. This method encompassed the study of several potential geometric systems, particularly those involving spherical shapes. These investigations were translated into models and empirical experiments, which were the primary methodological tool. In a departure from Kenneth Snelson, the potential application of these structures in architecture and engineering was explored, utilizing expertise from architecture.

In 1961, Fuller invented the "six-strut icosahedron" Tensegrity, which was subsequently developed further by others. This led to the conceptualization of vector equilibrium, a fundamental representation of Tensegrity structures in the context of architecture. This progression prompted Fuller to turn to design and explore applications and methods for creating novel forms. The exploration extended to the design of a geodesic dome based on Tensegrity principles, an endeavor that laid the foundation for the development of Tensegrity method. Fuller had the idea Tensegrity that could cover an entire city, but its realization was fraught with difficulties, mainly due to time and financial constraints. The construction of the Montreal Bubble at the 1967 Architecture Exhibition demonstrated the Tensegrity of the dome.

Figure 6 Fuller Richard Buckminster, 1968

Source: RIBA Collections

Figure 7 Geodesic Tensegrity Dome

Source: Fuller, 1953. Photo taken by Gengnagel, 2002

Figure 8 Geodesic Tensegrity Dome “U.S. Pavilion for Expo ‘67”

Source: Fuller, 1967. Photo taken by Cédric Thévenet

2.2 Theory

2.2.1 Definition of Tensegrity Structure

The definition, advantages and disadvantages of the tensegrity structure were also explored. The concept was defined as a structural principle developed solely on the basis of compressive and tensile forces, allowing an entire structure to connect, form and stabilize independently. The interconnected tensile forces create internal compression within the transmissive structure, while the compressive parts cannot be connected or touched. According to (Rene Motro 2003), the tensegrity system is in a stable, self-equilibrated state and consists of a discontinuous set of compressed components within a continuum of tensioned elements. The concept has also been defined by several scientists and consists of a string (under tension) and bars (under compression) (Skelton et al. 2001). Another key step in the tensegrity structure was to determine the geometric profile and initial compressive force through form-finding(Xu and Luo 2010). Previous research by (Koohestani 2012) also showed that tensegrity structure, mechanically stable and prestressed frameworks. (Ma, Chen, and Skelton 2020) proposed to design the simplest cantilever structure with tensegrity structures subject to yield and buckling constraints.

For many years, researchers have been trying to find a clear definition of tensegrity that is unambiguous and accepted in many fields. It is necessary to define what tensegrity is. A specific type of structure can be considered as an actual tensegrity structure. As in the previous example, there are many cases where the term tensegrity structure is incorrectly used for a structure based on push and pull elements. Tensegrity has its own unique rules. To demonstrate the change in the definition of the Tensegrity, the authors of this dissertation will present various definitions in descending order of time.

The first statement, described in Chapter 2, is defined by the patentee (Buckminster Fuller), who explains what he invented and demonstrated at the time.

It is difficult to understand and develop a complete definition Tensegrity complex components of tensegrity structures.

In an article titled Tensegrity by Buckminster Fuller in 1961, he outlines the rules and key concepts of the tensegrity system. However, he did not give a precise definition. He explained that such a structure was the abundance of intermittent prestressed columns of his patent. The structure of the infrastructure consists of three or more towers. And are connected by tensile elements. However, he then gave a brief description used in the history of Tensegrity structures, the compressed element is a series of tensile-closed structures, and years later, Buckminster Fuller wrote in The Synergetics book provides further explanation as follows:

Tensegrity is the relativistic law of structural geometry that can be identified by its fixed behavior consisting of the continuity of tensile forces in the system and the behavior of discrete or non-compact load carrier elements, not sticking together.

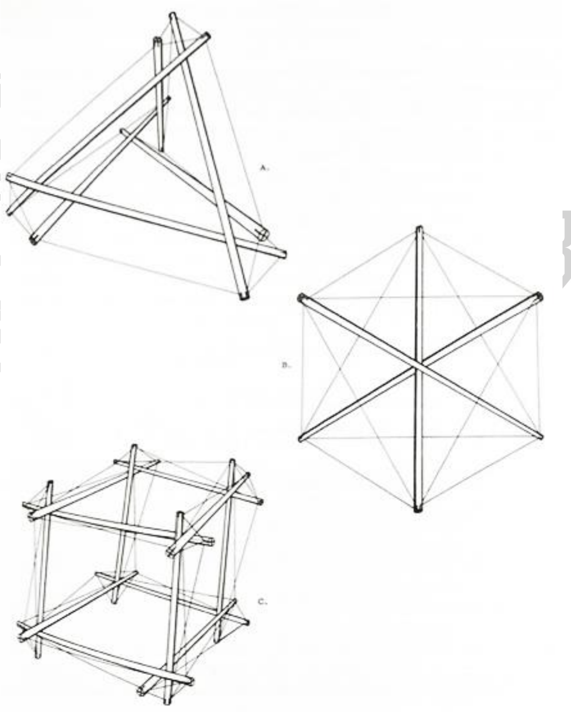


Figure 9 Fuller's tensegrities

Source: Synergetics: Explorations in the geometry of thinking. (Fuller 1982)

On the other hand, Kenneth Snelson describes today's innovations in the context of structural frameworks in his patent. This is especially true for newer structures where tensegrity structures are compression parts that are not attached or touching each other. The tensile sections are connected to each other and form a continuous tensile network. Although he likes to call it a floating compression structure, he further explained those things.

Tensegrity describes a structural system consisting of self-expanding and compressible support columns within a network of tensile tendons. In addition, as mentioned in the previous chapter, Kenneth Snelson has clearly explained that tensegrity structures are rigid structures with internal stresses. And such a restriction means that many other structures are not considered Tensegrity.

Figure 10 Kenneth Snelson in his studio on Spring Street with "Arcuate Lip Superstar,"

Source: Snelson, 1960

If the definition of Tensegrity constructs is accepted as sufficiently comprehensive, then it is important to distinguish between true and false Tensegrity constructs based on the following features:

System from theory relationship. This type of structure has the components of force in the system, including compressive and tensile strength. A state of stability resulting from the equilibrium itself. The Tensegrity can self-equilibrate without the need to do so. It requires external structural conditions. In other words, it can maintain its shape independently. It does not need a column to support it and is independent of external forces or even gravity. Composite material It can consist of poles, cables or membranes.

Continuous tensile force and discrete compression. The peculiarity of the force behavior in this type of structural system is that the compression components must be non-contiguous (non-contact) and the tension components must be continuous and connected tensile forces.

Strict adherence to the rules of the system. This is an essential point, for it distinguishes the two types of structure. It is a simple push-pull structure and a Tensegrity structure, many times over.

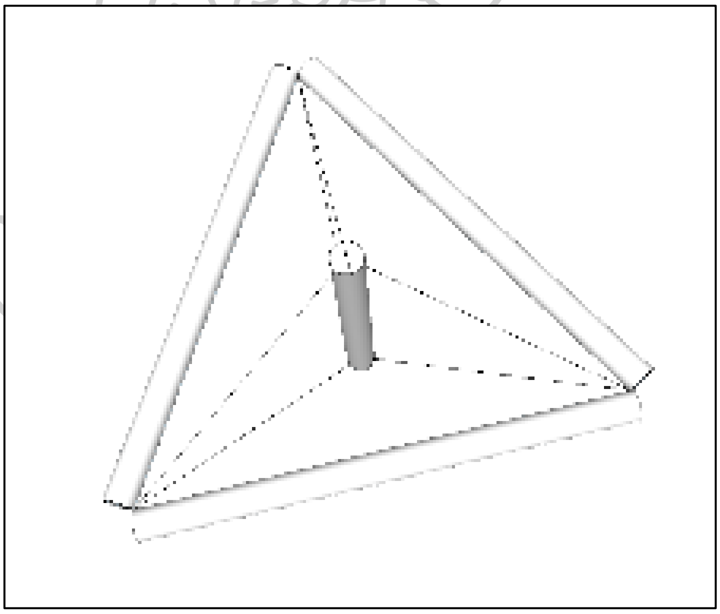


Figure 11 Octahedron

Figure 12 Georgia Dome by Levy and Weidlinger Associates

Source:https://www.tensinet.com/project_files/3755/small_GIORGI_ATLANT_WEIDLI_STADIU_PD01.jpg

Figure 13 Largest tensegrity bridge in the world, Kurilpa Bridge, Brisbane.

Source: Photo taken by Steve Collis from Melbourne, Australia. Retrieved from Wikimedia Commons.

2.2.2 Basic Principles

Since the middle of the 20th century, Tensegrity structures have been recognized that tensegrity structures exhibit special structural laws. One of the outstanding aspects is the surprising and poorly understood structural equilibrium of the system.

A basic example of Tensegrity structure works is the concept of rules used to control the structure. To understand the behavior of equilibrium in continuous tensile and discrete tensile structural systems. To analyze the forces acting at each point. Sometimes the study of the mechanism of the system can be complicated due to the geometric form and the number of structural elements. Therefore, it is necessary to use a computer program to accomplish this task.

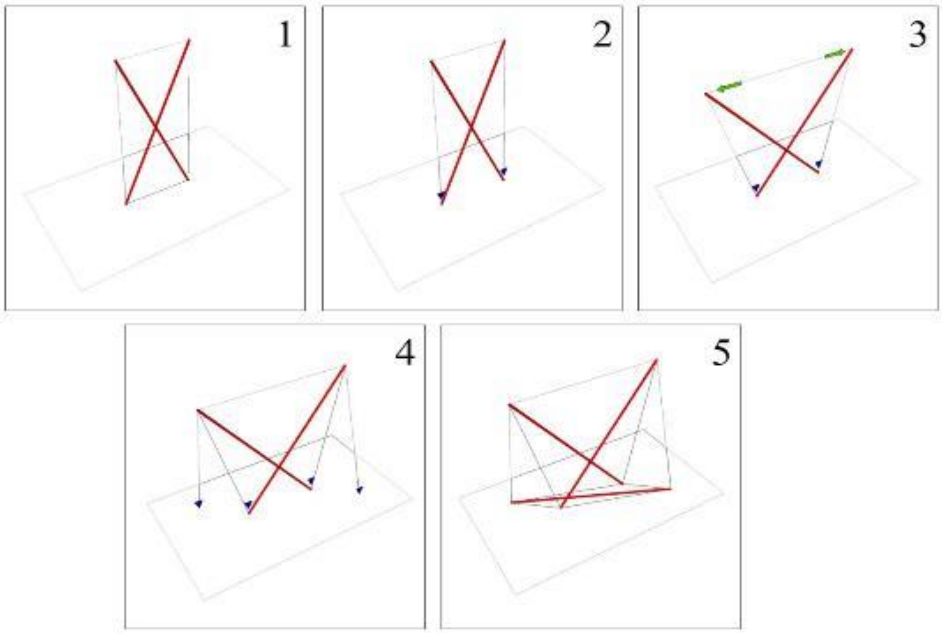


Figure 14 Basic concept of Tensegrity

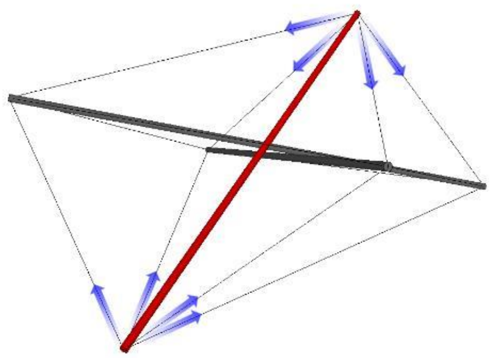


Figure 15 Basic concept of Tensegrity

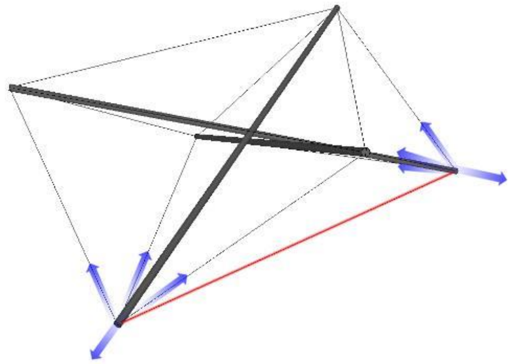


Figure 16 Basic concept of Tensegrity

Figure 16 illustrates the forces involved in this analysis, where a pull from each cable can support individual poles. Since this is a three-dimensional system, a cable is attached to the end of each pole. The resultant force at each point acting on both ends of the red pole must be in the same direction as the axis of the pole. Otherwise, the balance will not be achieved. It is as if we were holding the end of each toothpick with our index finger and thumb so that it does not slip out of our hand. The force exerted by both fingers on the tip of the toothpick goes in the direction of the longitudinal axis of the toothpick. The same reason can be applied to the red cable in Figure 31, where both ends of the poles are connected by cables and tensioned by at least three cables on each side. The result is that each wire is in equilibrium when subjected to the proper tensile force.

2.2.3 General Qualification

The structure is lightweighted compared to other structures with similar compressive and tensile loads. Compared to other structures of the same weight, this type of structure has a higher load-bearing capacity. The gravity of the Earth does not affect the Tensegrity structure as it is stable and self-balanced. It therefore does not need additional poles or cables to support the structure, as these systems are stable in all positions.

Most Tensegrity structures, which refers to the structure of the subunits that come together. They are arranged in pairs that mirror each other from left and right, as shown in Figure 17 (the Tensegrity infrastructure). They can be connected to form other different shapes. Furthermore, the compression force will increase as it increases itself.

The load-bearing capacity will also be high. The flexibility and strength of the structure depends on the material used. The assembly of these structures can respond to the overall composition as the force is transmitted evenly to the entire structure.

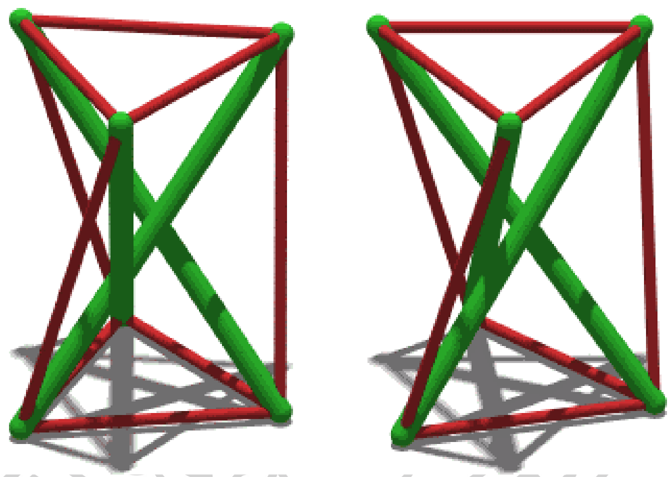


Figure 17 Basic structure Tensegrity

Retrieved from:

https://upload.wikimedia.org/wikipedia/commons/3/34/Tensegrity_simple_3_RL.png

2.2.3.1 Advantages

From a network of tension forces in all directions that acts like a pressure envelope. The structure is therefore flexible but remains stable at the same time. Due to the built-in structure, Tensegrity is a structure that uses little material but provides excellent strength, as these structures vibrate suddenly when a force is applied. This means that these structures can transfer weight or force instantly. This is therefore useful for absorbing vibrations, including vibrations caused by earthquakes. These structures are suitable for areas where there are problems with earthquakes.

2.2.3.1 Disadvantages

The complexity of fabrication is also an obstacle to the development of Tensegrity structures, as are problems with construction. Inadequate or limited construction equipment and tools are an obstacle in construction. Analyzing these structures so that the structure can support a large weight requires tools that can generate high compressive forces, which leads to difficulties in assembling the structure during large-scale construction.

2.4 Case Studies

Although the origin of Tensegrity mentioned in the previous chapter, including evolution and development, and is linked to events and situations, the content of this chapter will explain the possibilities. Bringing together modern and contemporary structures to be successful with the tensegrity structure from the Tensegrity.

An essential part of the Tensegrity structure is the pressure damper. Therefore, it is imperative to find a suitable material for the compression member that supports its tensile strength. Maximizing the efficiency of the compression and tensile structure may have seemed implausible before the 18th century due to material innovations in the 18th century. For example, logs that can withstand compressive and tensile loads are used, especially for the construction of ships that can withstand 10,000 psi.

Later, in 1851, iron began to be produced in large quantities until it became an industrial system that brought about significant changes. The steel can withstand up to 50,000 psi, both in terms of compressive and tensile strength. This feature has led to various construction styles, such as in engineering the Brooklyn Bridge, which opens the door to an era of innovation in traction design.

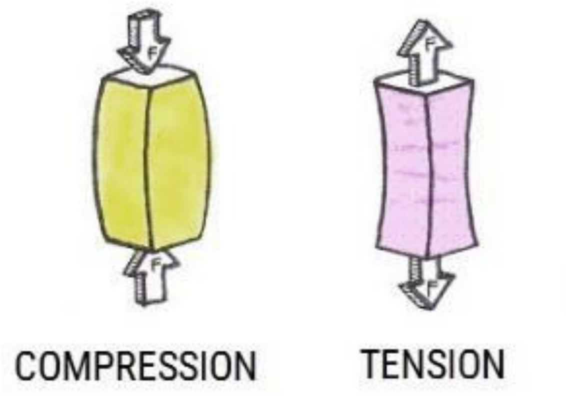


Figure 18 Compression tension

Retrieved from: https://www.eigenplus.com/force-work-energy/

The behavior of the elements under the weight differs depending on the type of force acting on the material. As shown in Figure. 20, the load-bearing material is subjected to compression in a straight line along the central axis. The object's body will converge in the center and bend the object and vice versa. If the same material is subjected to a tensile load in the same way, the flesh in the object's center will become thinner and expand. However, the most important thing is that the behavior of these two forces remains in the rectilinear axis. For this reason, the innovation of the material is essential for compression resistant applications where good anti-curve properties are required, and the tensioned part must be able to withstand tensile loads.

2.4.1 Compressive and tensile strength

An example of a suspension bridge in China, mentioned in the paragraph above, illustrates the force components in Figure 21. The suspension bridge later developed and increased the importance of tensile and compressive strength. The result is a cable-stayed bridge that uses cables to support the floor and also contains compressive forces. The floor of the bridge is therefore one of the components of the overall structure. It must be pressurized to achieve equilibrium, as shown in Figure 22.

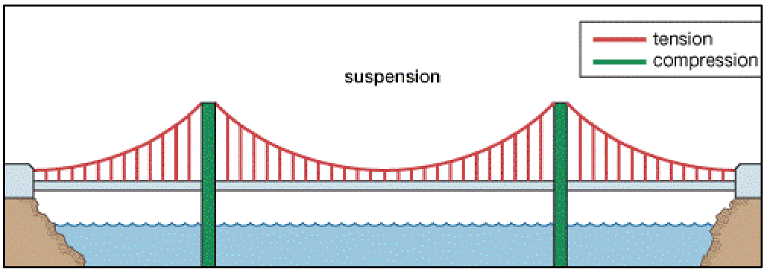


Figure 19 Suspension bridge

Retrieved from: https://www.britannica.com/technology/bridge-engineering/Truss

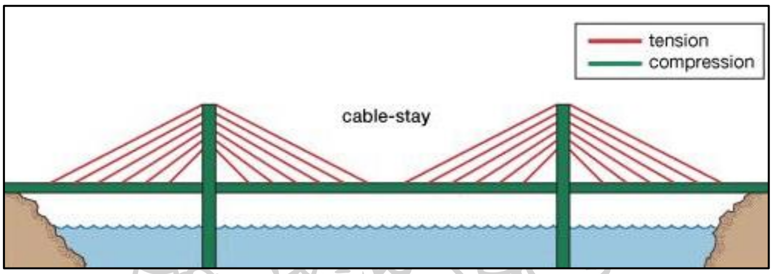


Figure 20 Cable-stayed bridge

Retrieved from: https://www.britannica.com/technology/bridge-engineering/Truss

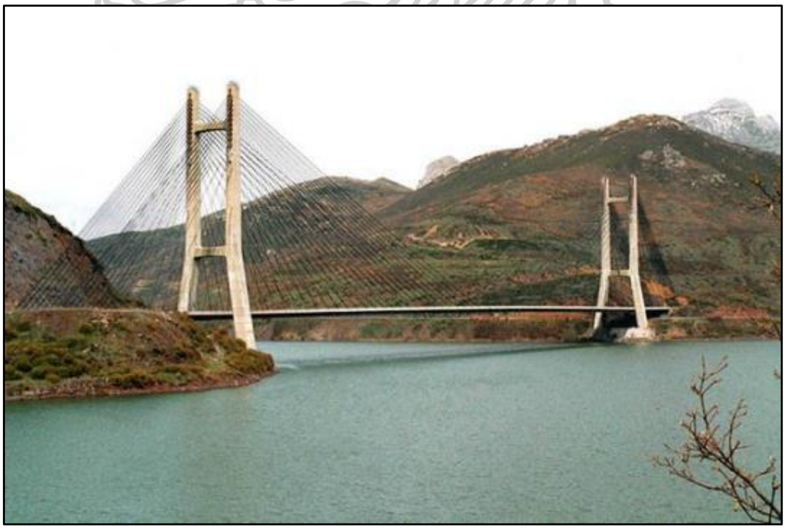


Figure 21 Barrios de Luna Bridge, Spain. Designed by Casado, built in 1983.

Source: Photo taken by Robert Cortright. Retrieved from

https://files.structurae.net/files/photos/2094/1729_barrios_de_luna_s0000648.jpg

An example of this is the Barriors de luna in Spain, built by Javier Manterola, which show an excellent use of compressive and tensile strength, as shown in Figure 23. The main piers of the two bridges are 440 meters apart.

Figure 22 Skylon Tower at Festival of Britain, 1951 designed by Powell & Moya.
Source: RIBA Collections, Photo taken by Millar & Harris.

Figure 24 shows the Skylon at an international exhibition held in London in 1951, three years after the official discovery of the Tensegrity structure. This work was created by Philip Powell and Hidalgo Moya. The Skylon was chosen as the best creation at the exhibition. After four to five years, it became a symbol of the exhibition and its technical possibilities. Eventually, it became a model for future generations of engineers and architects. The 300-foot tower resembles an aluminum shuttle bar. It hangs unbelievably from just three cables and appears to hover 40 feet above the ground. At the amazingness of this work, when you analyze the principles and systems of the force transmission interconnected structure under the three columns on the ground, using them as a cable sling to support the shuttle rod again. How much force is transmitted into the cable from all these structural forms? The shuttle bar is lifted higher. At the same time, the three columns and the shuttle are responsible for the compressive forces transmitted by the cable.

This structured layout reduces by more than half the need for cables holding the shuttle bar body to keep it from swaying. Previously, the cable may have had to be attached to the shuttle bar and connected directly to the ground. In the latter case, the cables between the shuttle bar and the ground must also be attached to each line in balance.

2.4.2 Suspended roofs and tensile structures

In the 1950s, cables began to be used to pull membrane or canvas materials. In the 1950s, a design of this type was presented in Fair Arena, North Carolina, by Matthew Nowicki. It was based on the concept of building a sagging roof. In the same year, students at the Faculty of Architecture in Germany became aware of this sketch. During the exchange program in the United States, he was very enthusiastic and impressed by this innovative idea. As a result, he began to study this type of work systematically and presented it in his doctoral thesis in 1952. His name was Frei Otto.

The Center for Lightweight Construction was founded by Frei Otto five years later in Berlin and merged with the Institute for Lightweight Shell Structures at the University of Stuttgart in 1964 to strengthen research in applied architecture. Therefore, some important materials were developed for their tensile properties, especially steel, but also polyurethane, polyester, PVC, fiberglass and cotton. One project is a tent-like structure with four corners and is used at the music festival, the Federal Garden Exhibition, Kassel, Germany in 1955.

Figure 23 Music Pavilion at the Federal Garden Exhibition, Kassel, Germany

Source: Frei Otto, 1955

Figure 24 German Pavilion for Expo'67

Source: Frei Otto, 1967

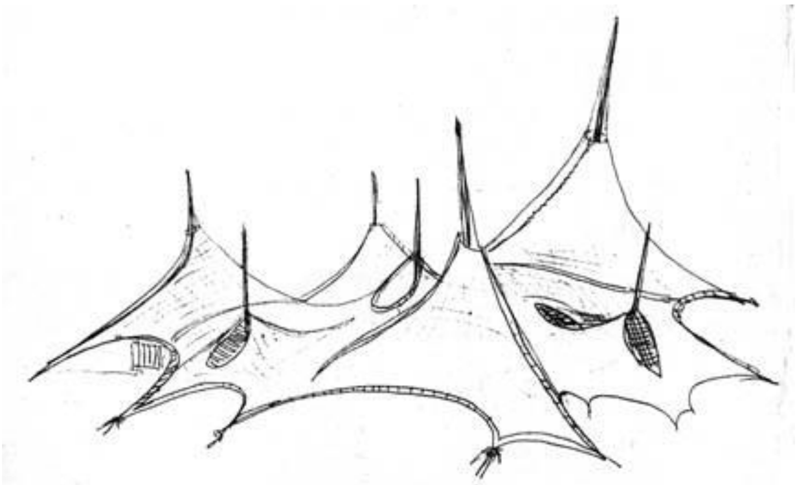


Figure 25 German Pavilion for Expo'67

Source: Frei Otto, 1967

The first large cable construction made of fiber material took place in the German Exhibition Hall of the World's Fair in Montreal, which was built by Frei Otto in 1967. Although these projects are not considered Tensegrity structures, they are important for the development of Tensegrity structures because this type of membrane can be used as a structural element in the tensile segment.

Although these projects are not considered Tensegrity structures, they are important for the development of Tensegrity structures, as this type of membrane can be used as a structural element in the tensile segment.

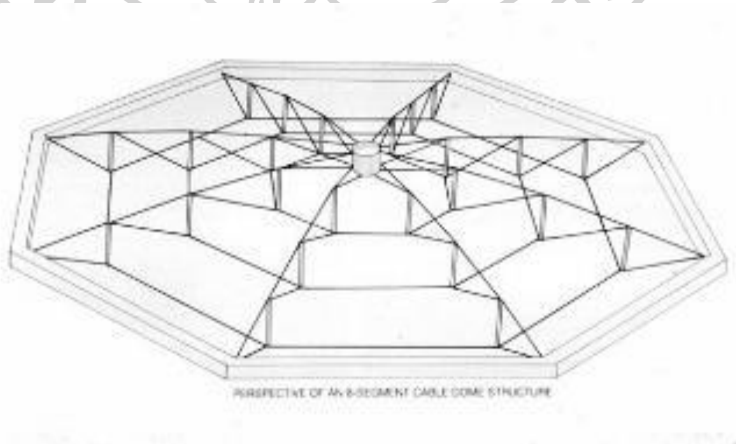


Figure 26 The Geiger Cable-Dome

Source: https://www.instructables.com/The-Geiger-Cable-Dome/?li_source=base&li_medium=related-instructables&li_campaign=related_test

Cable dome or dome that looks like a wire wheel It was invented by David Geiger in 1986. Since then, several more domes have been built using this technique, in which the principle of load-bearing beams are connected to the outer ring and gradually connect the inner core ring to link the entire shed building together.

Because of this structural form factor, some architects and engineers consider cable domes to be Tensegrity structures. However, when analyzing the principles of Tensegrity, cable domes do not qualify because the Tensegrity structure has a compression component to its perimeter.

The reasons for this controversy are outlined in the next section where Kenneth Snelson was interviewed on the subject. He did not agree that it was a Tensegrity Structural System.

Figure 27 Cable dome structure model

Figure 28 Georgia Dome by Levy and Weidlinger Associates

Source: https://bleacherreport.com/articles/2359020-redskins-rg3-less-fan-letter-may-spark-new-nfl-truth-in-advertising-trend

Figure 29 Georgia Dome by Levy and Weidlinger Associates

Source: https://www.ajc.com/sports/football/georgia-dome-demolition-planned-next-year/8lvoF3t12lj2Mo5T0JBzdL/ Photo taken by Daniel Varnado

This type of structure is different from the tensegrity structure, as can be seen from the premise of the basic law of the tensegrity structure. This accepts continuous tensile strength such as cables, which in the case of cable dome structures are continuous compression members compared to the outer ring of this structure. This is a violation of the definition or structure of Tensegrity. The first cable dome was designed by David Geiger in 1986 for the Seoul Olympics, followed by the Redbird Arena in Illinois, the first elliptical cable dome, and the Florida Sun Coast Dome in St. Petersburg in 1988 and the Taoyuan Arena in Taiwan in 1993. The largest dome in the world to date is the Georgia Dome in Atlanta (1992) by Levy and Weidlinger Associates.

2.4.3 Tensegrity Furniture

The unique characteristics of Tensegrity Structures, which involve both compression and tensile forces, can present challenges for integration yet also offer intriguing opportunities for designers.

Figure 30 Tensegrity Furniture
Source: Cassina 713 coffee table by Theodore Wadell, 1973

Chapter 3

Research Methodology

3.1 Research Methodology

This research was conducted by combining primary methods with the objective. Furthermore, the tensegrity structure was to tensegrity for further architectural applications as a long-span building to cover an area with different shapes. This was necessary as the original design had some limitations, such as the complicated installation method, which led to less popularity despite its potential as one of the most efficient structures. The six main stages that were used are classification, data collection, hypothesis, experiment, result and delivery, as shown in the following figure. The first step was to categorize the tensegrity structure as the concept needed to be described, defined and classified for further development. It was also necessary to ensure a more controversial and consistent classification. Therefore, this research attempted to make an opinion-based categorization, focusing on the expansion direction of shape and form, as well as analyzing the ability of each system to facilitate change. The second step focused on using the data from the categorization considering the initial requirements of the systems to find the gaps or directions in the design in order to provide a new type of tensegrity structure with the ability to respond to comprehensive architectural applications. The third step was to formulate the hypothesis: “What direction or design concept is expected from the new tensegrity structure?” The data from the classification made in the first step was analyzed to speculate on the feasibility of the experimental design. The fourth step was to conduct experiments on the physical and behavioral effects of the structure through modeling. The fifth step focused on evaluating the results to ensure that the objectives were met. The discovery of an unmet objective would lead to a thorough investigation of the methods used for errors, followed by conducting another experiment. The sixth step was to analyze the data obtained from the evaluated results to ensure that the hypotheses made were agreed. The discovery of a mismatch would lead to a re-evaluation of the concepts, methods and results. The well-designed process was necessary for effective research as it can monitor and support the experiments. The process began with gathering information for classification, followed by examination and exploring the properties of each type in order to develop a new design.

3.1.2 Qualitative Research

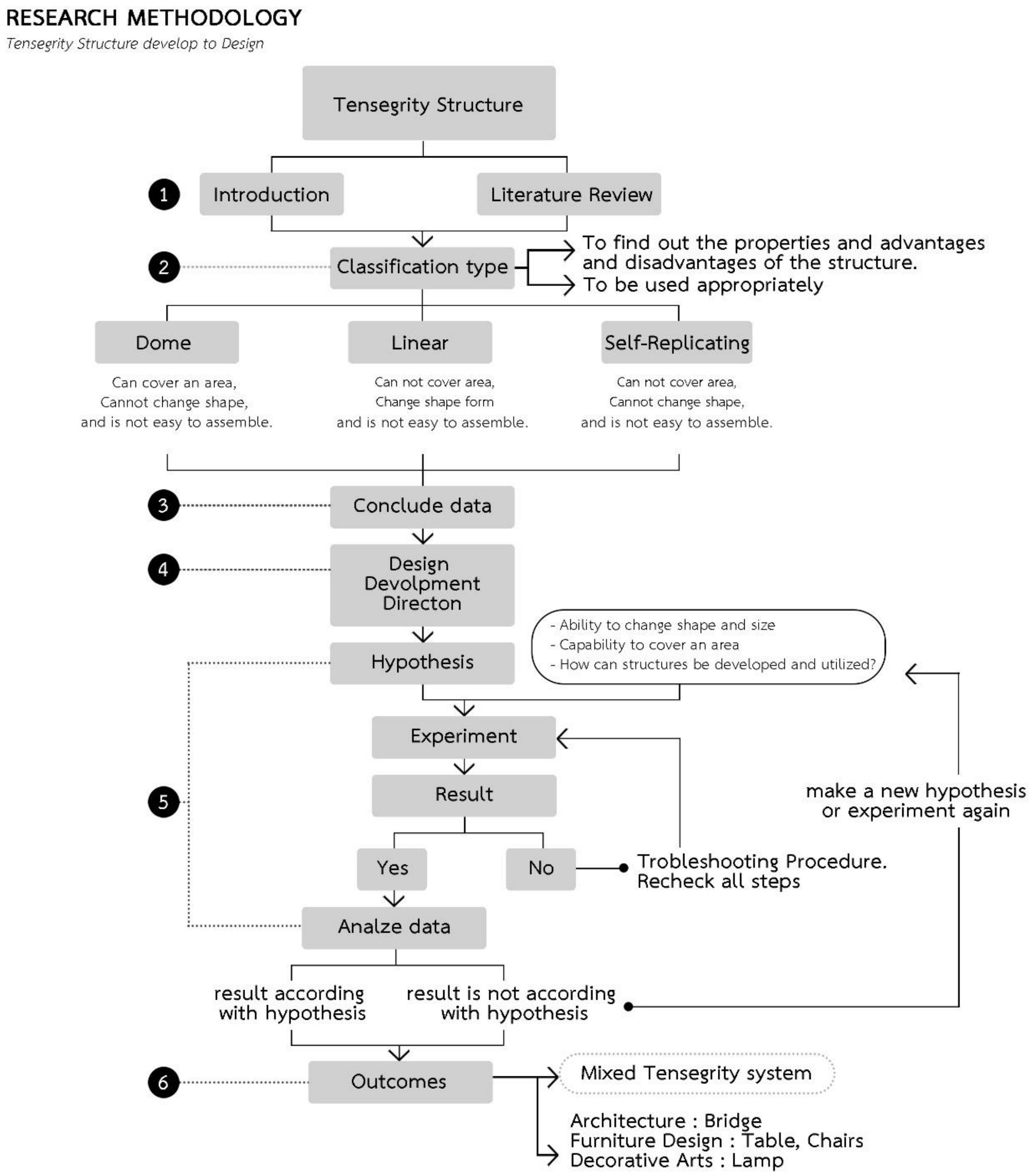


Figure 31 Design Research Process

This research initiative undertakes a qualitative experimental exploration using methods such as observation and experimentation to systematically investigate the integration of tensegrity structures in different design domains. The overall aim is to advance the development of tensegrity structures, particularly in the fields of architecture, engineering, industrial design and other creative disciplines. The research is characterized by conducting experiments and testing hypotheses to evaluate the feasibility of tensegrity structures. The study draws inspiration from the inherent structural principles observed in bone structure, the muscular system and human movement, and seeks to merge these concepts with the fundamental principles of tensegrity.

The qualitative data presented in this study is derived from the application of structural principles to furniture design. It has undergone rigorous real-world scrutiny to uncover innovative challenges and identify new key themes in practical application. Various research methods have been applied in this investigation, which include exploring the origin and definition of structures, classification based on their properties, data collection and synthesis, design development and the formulation of experimental hypotheses. Additionally, the study introduces concepts derived from the application of tensegrity structures.

3.2 Design Conceptual

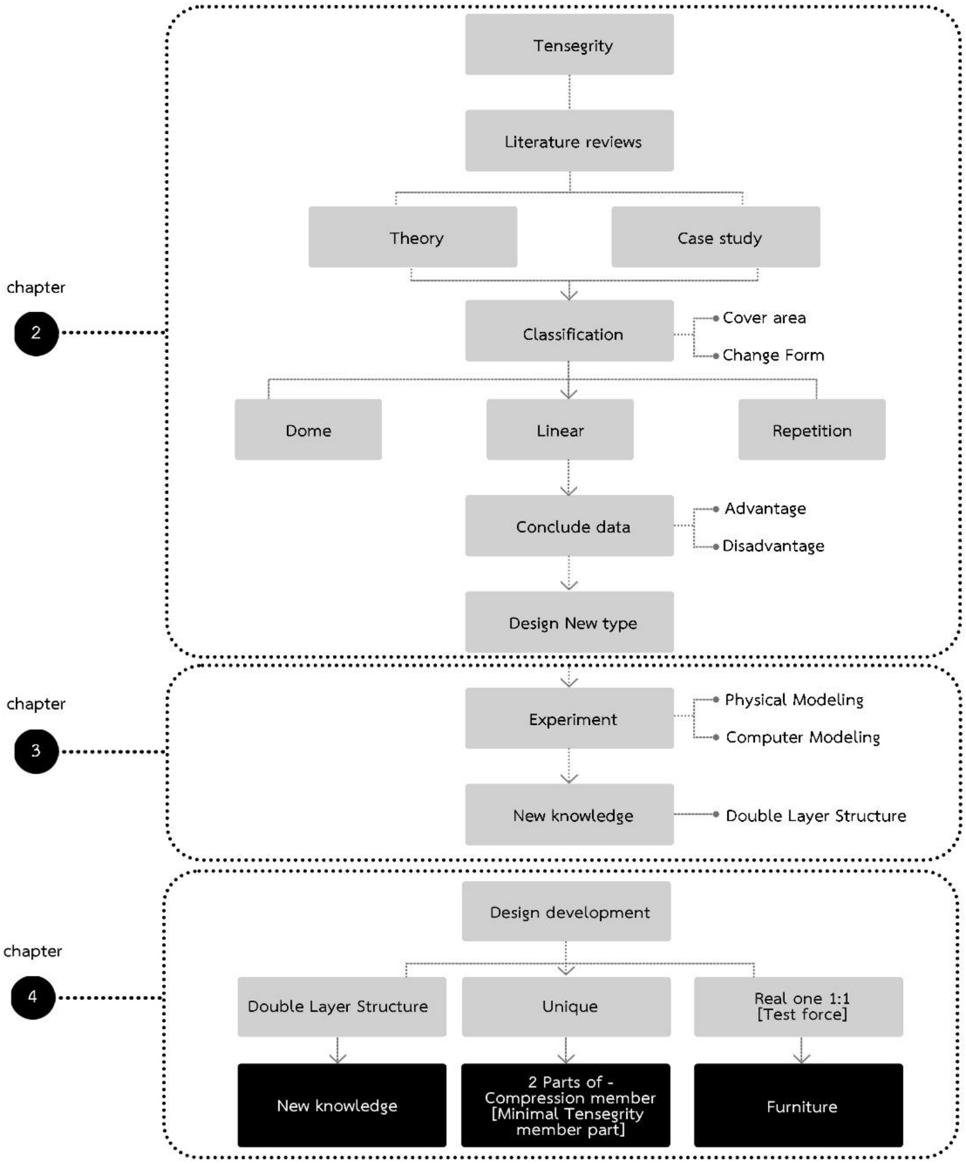


Figure 32 Research framework

The conceptual framework presented in this research establishes a theoretical foundation for the designs and establishes a meaningful link between the proposed designs and biological and structural principles. The research makes a significant contribution to the advancement of tensegrity structures by introducing new applications, including their integration into furniture design, and presenting various designs derived from tensegrity principles.

3.3 Design Process

3.3.1 Design Process in the 1st step: Exploration

3.3.2 Design Process in the 2nd step: Classification of Tensegrity Structure

An essential aspect of knowledge development in a new field is description, definition and categorization in order to create a comprehensive classification and broaden the scope of investigation. Similar to Tensegrity structures, the current classification among numerous experts remains contradictory and inconsistent. This study investigated the author's point of view by considering various characteristics, especially the direction of the extension of the shape and form of the structures.

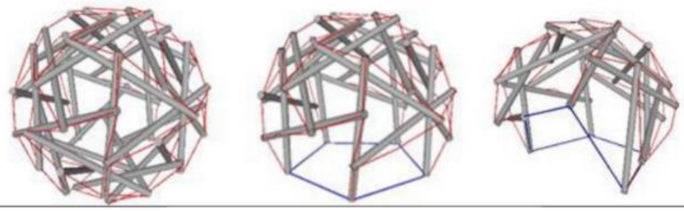
Name	Type
Tensegrity dome system	
Tensegrity linear system	
Tensegrity, Self-Replicating System.	

Figure 33 Presents the categorization of Tensegrity structures.

3.3.1.1 Tensegrity Linear System

Linear system Tensegrity is characterized by the connection of subunits in certain directions. Each subunit is connected to the central unit of the structures in such a way that the inclusion of only 1 unit is sufficient to maintain structural equilibrium, unlike the dome system. In this method, the subunits are connected to each other in the form of plates, so that three or more subunits are required to achieve structural equilibrium. This particular feature of linear Tensegrity structures is made possible by the interlocking points within the subunit connection pattern. The points facilitate the attachment and compression of the components within the structures, with a higher number of points compared to the Dome Tensegrity. The linear Tensegrity system has more than one connection point between the subunits corresponding to the direction of the lines of force.

The connection nature of the linear system Tensegrity-out technique to increase the range. This requires connections that are oriented in the direction of the recoil force to ensure an even distribution of force. An influential figure in this type of structure was Kenneth Snelson.

The thinking underlying his work, although primarily sculptural, plays a crucial role in transferring this concept to the further development of Tensegrity structures in the field of architecture and engineering.

3.3.1.1.1 Variety of Subunit Tensegrity Line System

Tensegrity subunits of linear systems take different forms. The dimensions and orientations of the joints can vary, but what they all have in common is that they rely on compressive forces to expand. This rebound mechanism expands where the displacement force is clearly in the direction of the structures.

3.3.1.1.2 Connection of Linear System Tensegrity Subunit

Delving into Tensegrity subunit, the linear system has a basic working principle, namely the synergistic application of continuous tensile and discrete compression principles, as stipulated by Tensegrity structures.

A critical point of Tensegrity system structures is the way in which the subunits are connected to each other. Tensegrity systems are characterized by the fact that they connect the subunits exclusively by direct connection and thereby maintain structural equilibrium. It can be observed that the subunits of the tensegrity system can expand or contract at any time within the linear system. The inherent nature of the structures eliminates the need for a third unit or external support for the addition and splicing process. This distinguishes it from Tensegrity dome system, which requires at least three subunits for shaping and self-propulsion.

Figure 34 Connection of linear system Tensegrity subunit

3.3.1.1.3 Subunit Connection of Tensegrity Linear Systems

Another capability of the Tensegrity is the manipulation of the connection direction to increase the number of subunits. In this section, the control of the direction of Tensegrity line system can be categorized into two types, namely twisting, and turning. Coordinated control of both types is an important aspect of controlling the system.

3.3.1.1.4 Controlling the Rotation Direction of the Linear System

The torsion of a linear Tensegrity is the change in degree of the entire structural axis. However, the direction can be inconsistent and extend from the head to the tail. This is achieved by rotating the units, a method used to create different angles between the pressure components within each unit. The twisting of Tensegrity linear system ensures that the overall length of the cable remains the same in each subunit. The installation of the subunits can result in the overall shape of the subunit being asymmetrical while maintaining the same center force point.

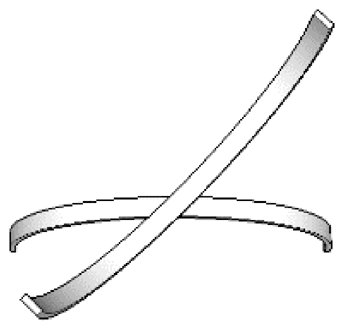


Figure 35 Controlling the rotation direction of the linear system Tensegrity subunit

Figure 36 Controlling the rotation direction of the linear system Tensegrity subunit

Figure 37 Controlling the rotation direction of the linear system Tensegrity subunit

Figure 38 Controlling the rotation direction of the linear system Tensegrity subunit

3.3.1.1.5 The Twist of the Linear System Tensegrity Unit

Tensegrity turn Line system involves the diversion from the position of the newly added unit or the linear axis of the starting team.

Figure 39 The twist of the linear system Tensegrity unit

Figure 40 The twist of the linear system Tensegrity unit

A technique was used to determine the length of the compressed parts within the unequal unit by a twist in the linear system Tensegrity unit. This causes the newly installed unit to deviate from the axis of the original force center. Essentially, the torsion of Tensegrity linear system tensegrity affects the overall length of the cable in each subunit, accompanied by uneven spacing and angles of the compression components. This manipulation, combined with the symmetrical shaping of the compression components, ultimately gives the Tensegrity Linear System the ability to perform twists.

3.3.1.1.6 Advantages and Disadvantages of Tensegrity Linear Systems

The ability to connect subunits with more than one connection point per direction of the line of force allows the number of subunits to be increased or decreased as required, contributing to robustness. Tensegrity linear systems are well suited for working over a large area. It also allows the structural direction of rotation to be defined while maintaining stability and balance. It is worth noting that the process of assembly and installation chosen for these system structures is complicated. The arrangement of parts can also be complicated, especially when working with heavy loads.

3.3.1.1.7 Summary of Tensegrity Linear Systems

Tensegrity structure was found to have linear expansion properties and its ability to change shape was also considered an advantage. However, the structure was unsuitable for surface application due to complex internal connections and binding forces within each subunit. The connections were typically bidirectional (forward and backward) in a full 3D representation, allowing for free expansion, contraction and change of shapes. The structure required no interrelationships, albeit at the expense of overall structures, depth, spacing and complexity of connecting forces between the cable and compressive loads.

Figure 41 Connection of Linear System Tensegrity Subunit

3.3.1.2 Tensegrity Dome System

These systems are considered spherical. The elements of the subunits cannot be added, as they remain connected to each other until the system has reached its completion. This configuration leads to a round shape and culminates in the formation of fundamental structures (geodesics), as shown in the work of Buckminster Fuller.

This type of structure is characterized by the agglomeration or connection of the individual units, which are linked together in the form of sheets, facilitating their cohesion. A spherical shape is essential for these structures, as they rely on the force compressing the subunits evenly from all sides to create structural stability and maintain the form.

3.3.1.2.1 Tensegrity Subunit Dome System

As in the figure 52 showing the subunit of Tensegrity structures, the dome system consists of three tension and compression columns. The red line indicates the compressive force exerted on the gray columns, which leads to the overarching structures and the self-pressure of the subunit.

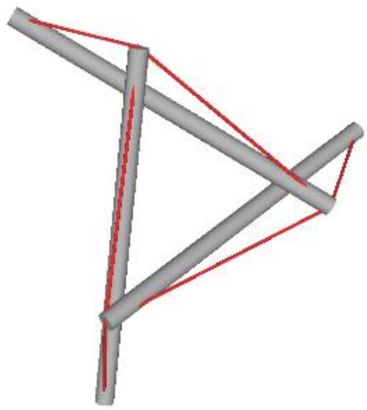


Figure 42 Tensegrity subunit Dome system

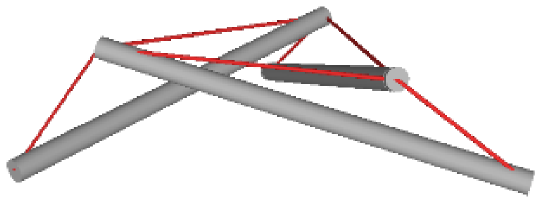


Figure 43 Tensegrity subunit Dome system

3.3.1.2.2 Subunit Connection of the Tensegrity Dome System

Tensegrity structures allow the individual subunits to be connected at the designated blue marker. One subunit can be connected to three others, allowing infinite connections. The resulting structures take on a round and spherical shape, with the direction of the pressure exerted by the gray columns of each unit forming a geometric pattern.

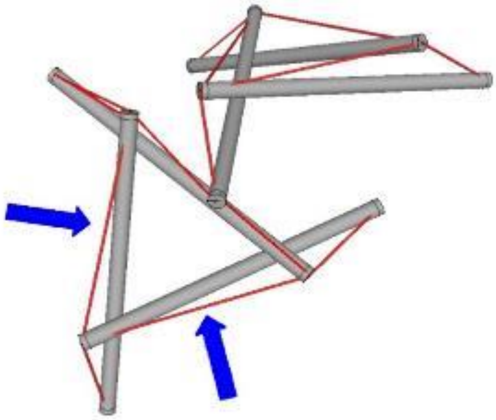


Figure 44 Connection of Tensegrity Subunit Dome System

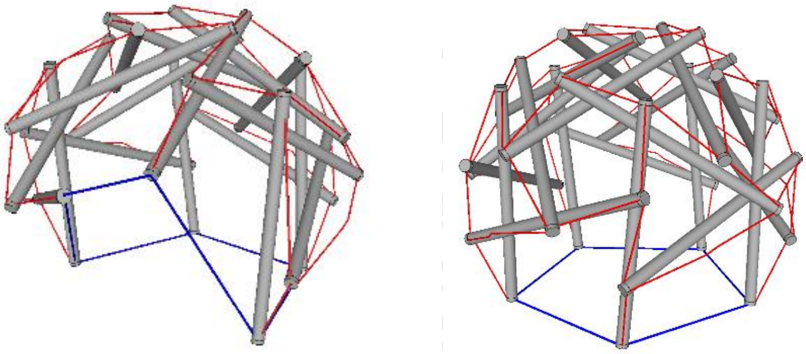


Figure 45 Geodesic Tensegrity Dome

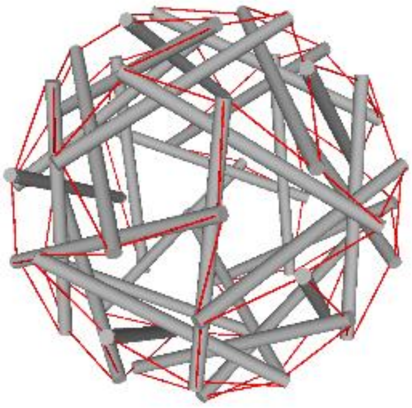


Figure 46 Geodesic Tensegrity Dome

As in Figure 47, the dome-shaped structures are formed by the connection of subunits that do not form a complete system, but rather a dome or a hemisphere. The overall structures cannot hold their shape or support themselves. The lack of internal forces prevents the structures from joining together to form a coherent network. Consequently, the tension of the blue cable allows the structures to push upwards and maintain their shape.

3.3.1.2.3 Advantages and Disadvantages of Tensegrity Dome System

The ability of this type of Tensegrity is essential for end closure spaces. Nevertheless, the dome system has a disadvantage in connecting the subunit. Figure 57 shows that four columns under the structures raise the whole structure with five columns. In this case, a subunit in contact with the ground would be removed, even with the support of the blue cable to maintain the pressure of the structures. Despite these efforts, it is not possible to maintain the overall stability, including maintaining the shape that has been distorted by the imbalance due to the incomplete connections of the subunits.

The connection of asymmetric subunits cause tensive fluctuation on at both ends of the blue cable. This unequal point force, when consistently transferred to other sections of the structures, leads to a lack of equilibrium as there are no opposing forces. Consequently, the structures become unstable and fail to maintain equilibrium at full efficiency as previously achieved.

3.3.1.2.4 Summary of Tensegrity Dome System

The Tensegrity Dome Structure was characterized by its ability to expand into a spherical shape covering a surface without changing its shape. The subunits within the structure were interconnected as plates, resulting in an advantageous overall shallow depth. However, an important drawback was that each subunit had to maintain a complete equilibrium. If this equilibrium was not achieved, the entire structure could not maintain its intended shape. The subunit structure prevented the set from maintaining its shape, so the compressive and tensile forces of the other subunits had to converge, necessitating the spherical design.

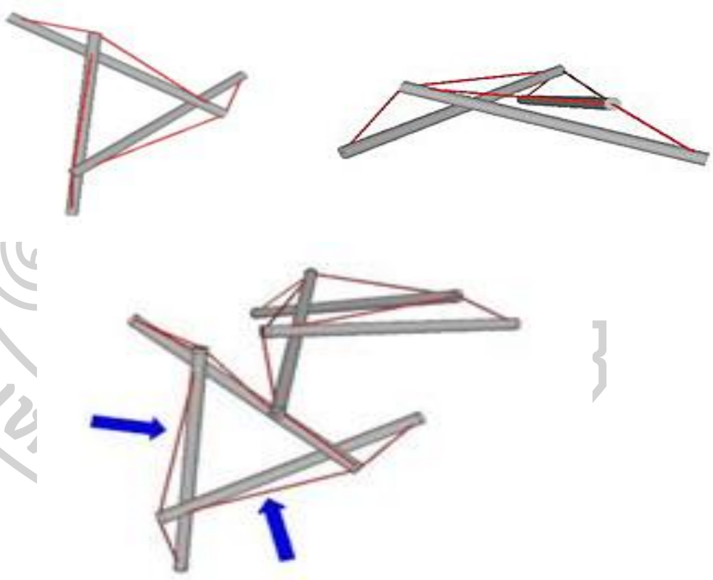


Figure 47 Tensegrity Subunit Dome System

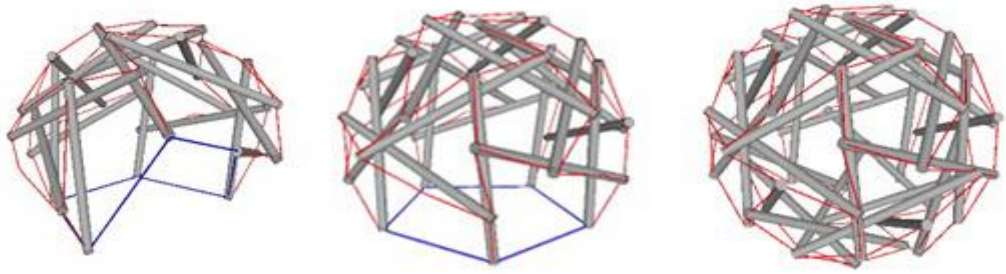


Figure 48 Geodesic Tensegrity Dome

Figure 49 Geodesic Tensegrity Dome

Figure 50 Geodesic Tensegrity Dome

Figure 51 Geodesic Tensegrity Dome

3.3.1.3 Tensegrity, Self-Replicating System

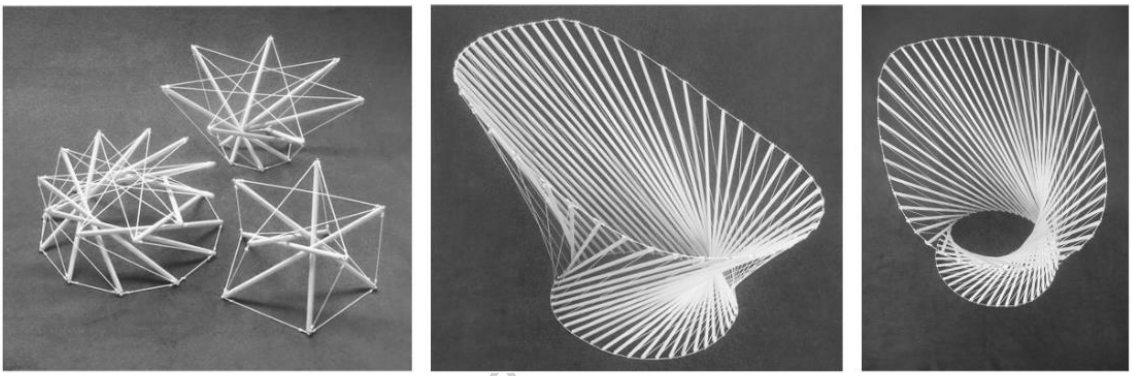


Figure 52 Connection of Linear Tensegrity Subunit System

Source: Marcelo Pars

This system is characterized by a simple, easily understandable and self-contained structure. The entire system consists of only one unit, which can be expanded by increasing the number of parts or by enlarging it with compression parts. Enlargement means increasing the number of compression components within the same structures. This can be achieved by a method that ensures compression along the same load line. This particular system is called self-repetitive Tensegrity to its repetitive patterns for increasing the number of compression components within structures. This system is used in sculpture and structural modeling. It also serves as an excellent starting point for Tensegrity structures as it is easy to understand.

3.3.1.3.1 Form of Tensegrity: self-repetitive system

The self-repetitive systems can manifest themselves in various shapes, but they all fulfill the basic requirement of being Tensegrity structures. The entire structures consist of continuous tensile forces and intermittent compression. Unlike the dome-shaped or linear Tensegrity systems mentioned earlier, the structures of the self-repeating system have only one form unit of compression and tension. If you extend the structures of Tensegrity systems, the number of subunits increase. However, this system uses the method of increasing the number of pressure columns in the original structures. The self-repeating property makes it unnecessary to consider the connection to other units, resulting in a simplified stress curve within the structures. This also makes the structures easily accessible for study and analysis.

3.3.1.3.2 Increasing the Number of Compression Parts in the Tensegrity Self-Replicating System

The repetitive system in Tensegrity structures works on the premise that pressure components are added while structural equilibrium is maintained. An illustrative example Tensegrity three pressure columns. As you increase the number of compression columns in the system, the shape changes from the end of the column. In this process, the internal compression within the structures affects the compressing cables. The additional compression columns can be compared to replicating the layout of the existing columns by simply shifting an additional angle to the additional columns. This method opens up new space to distribute the forces and facilitate their dispersion.

3.3.1.3.3 Advantages and Disadvantages of Tensegrity Self-Replicating System

The special feature is the addition of compression components within the structures while maintaining the number of tensile elements. This method provides more stability, but sometimes increases the number of compression columns in some structures. This can lead to a reduction in available space within the structures as the compression columns lean back and forth, resulting in less space efficiency in terms of architecture. This aspect is a crucial consideration when opting for Tensegrity in architecture. The expansion method, where the components are extended within the structures, can cover a large area but does not achieve optimum efficiency in all cases.

3.3.1.3.4 Summary of Tensegrity, self-replicating system

Figure 53 Tensegrity, self-replicating system

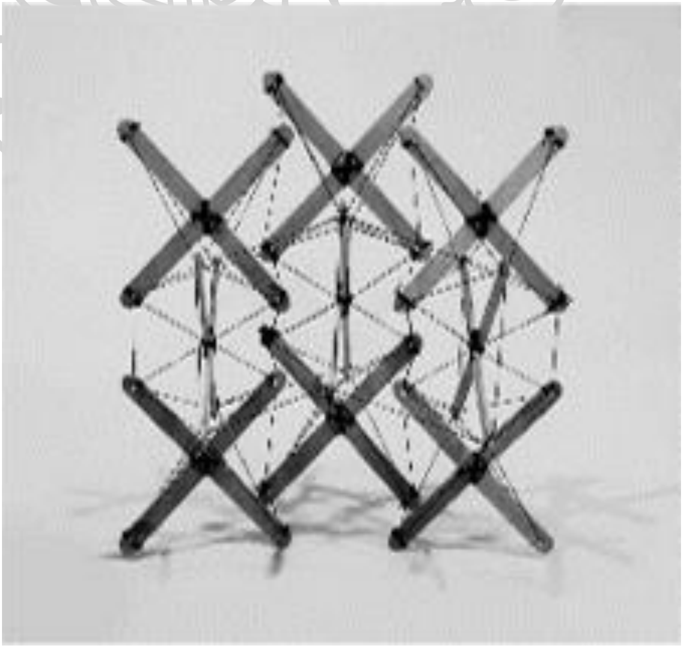


Figure 54 Tensegrity, self-replicating system

Figure 55 Tensegrity, self-replicating system

Figure 56 Tensegrity, self-replicating system

Figure 57 Tensegrity, self-replicating system

Figure 58 Tensegrity, self-replicating system

3.3.3 Design Process in the 3rd step: Collection and Synthesis of Data

The classification of Tensegrity structures is based on expansion or extension of parts within a Tensegrity structure so Tensegrity structures can be divided into three central systems.

1. Tensegrity structure, a dome system that has the property of expanding into a spherical shape that can cover the area but cannot change its shape.

2. Tensegrity Structure Linear system that has the property of expanding linearly and changing shape direction but cannot cover an area.

3. Tensegrity structure, self-repeating system A system structure can have many shapes. The basic shape of the structure itself is the shape of a system structure that expands by stretching the length of the components inside the structure. It can increase the number of compression parts within the original force line. It can be said that this system structure can cover space and change its shape. Nevertheless, the advantage of this system structure is the ability to increase the strength of the structure. This means that the number of pressure components within the structure is increased within the original force line. This makes the overall structure stronger. In

other words, the structure can cover a larger area or extend over a larger area.

Collecting and classifying the properties of Tensegrity Structures is beneficial for further development and design, as it facilitates understanding of the advantages, limitations, and initial applications of the structure. Preliminary experiments have facilitated the classification of Tensegrity into three types of structures: 1. A dome system used to cover an area, exemplifying the use of Tensegrity structures for expansive spatial coverage. 2. A linear connection system, which can be utilized in sculptures or any form requiring elongated connectivity. 3. Self-repeating system, suitable for designs that demand uniqueness among their components. This classification not only highlights the versatility of Tensegrity structures but also aids in pinpointing specific applications suited to each type.

3.3.4 Design Process in the 4th step: Design Development

The concept of compressive and tensile structures, a distinctive characteristic of Tensegrity Structures, provides the foundational framework and principles for designing analogies to the human body. For instance, the human bone structure functions as a solid, while the tension from muscles and tendons within the body creates a strong and flexible system akin to Tensegrity structures.

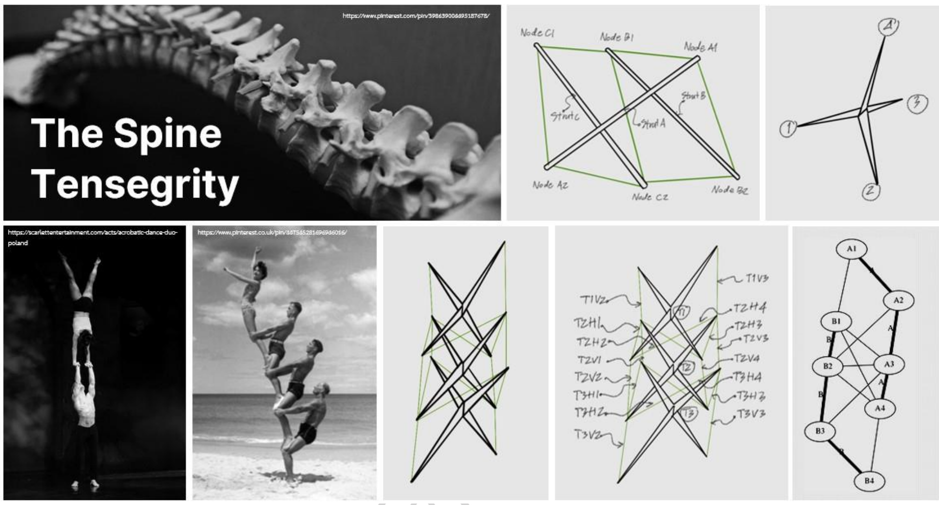


Figure 59 The Spine Tensegrity concept

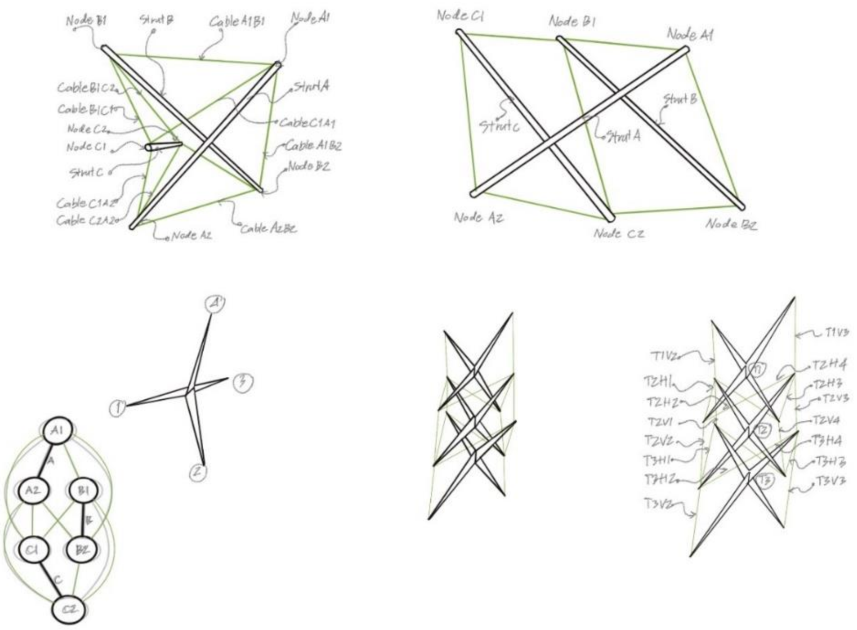


Figure 60 The Spine Tensegrity Sketch

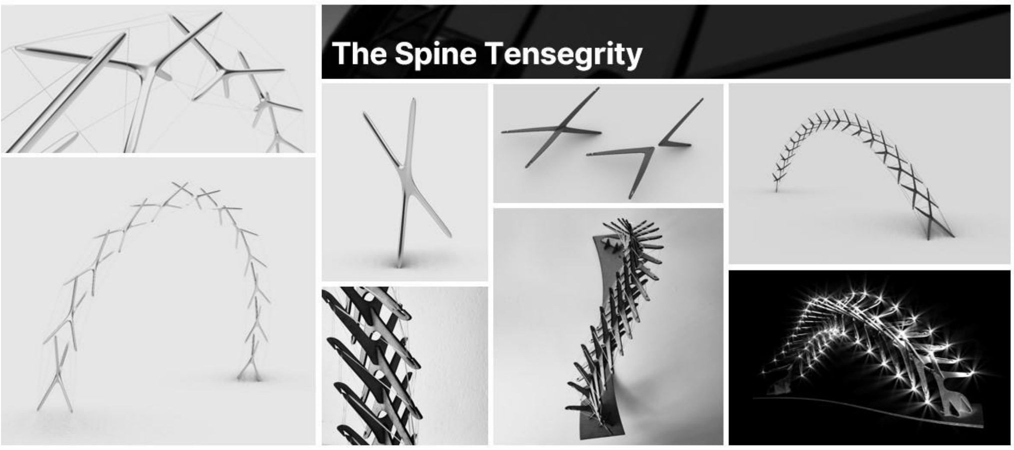


Figure 61 The spine Tensegrity concept

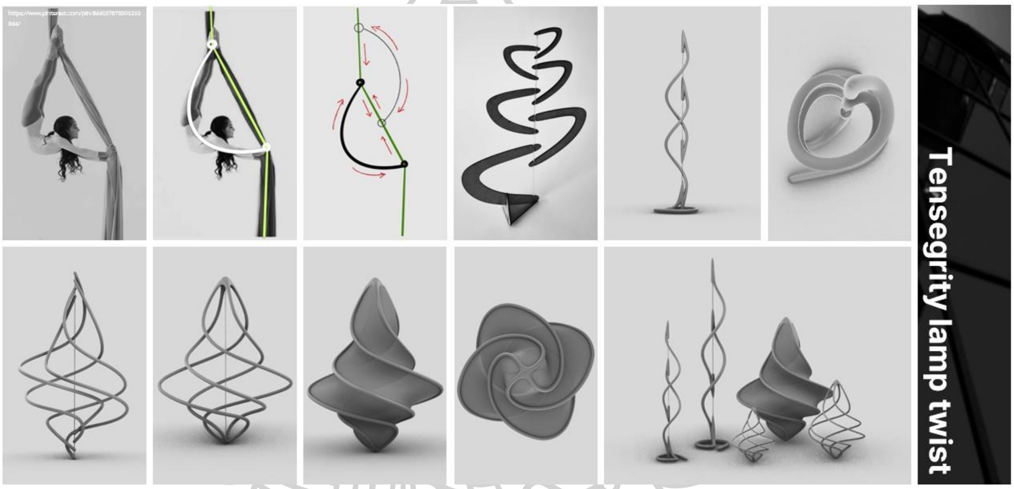


Figure 62 Twist tensegrity lamp

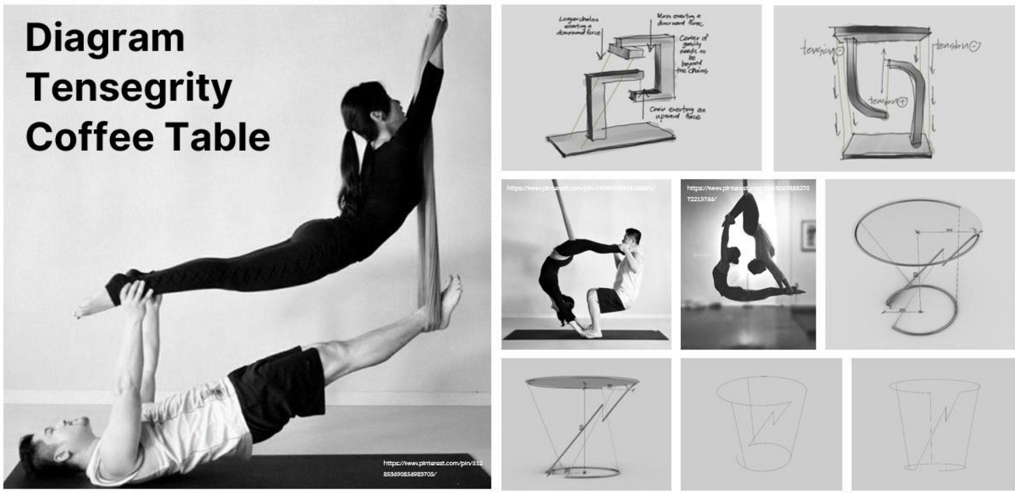


Figure 63 Concept framework of Tensegrity coffee table

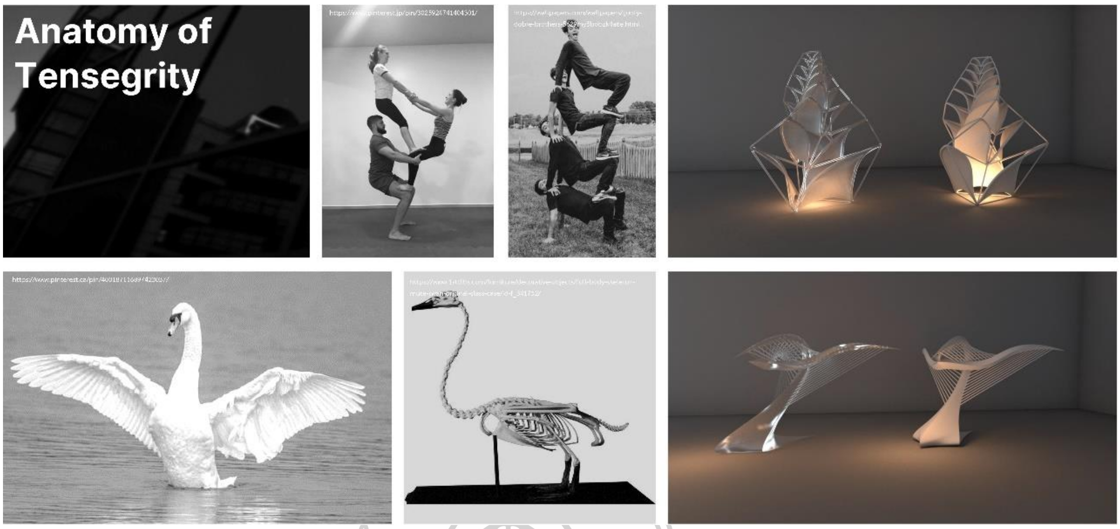


Figure 64 Anatomy and Tensegrity

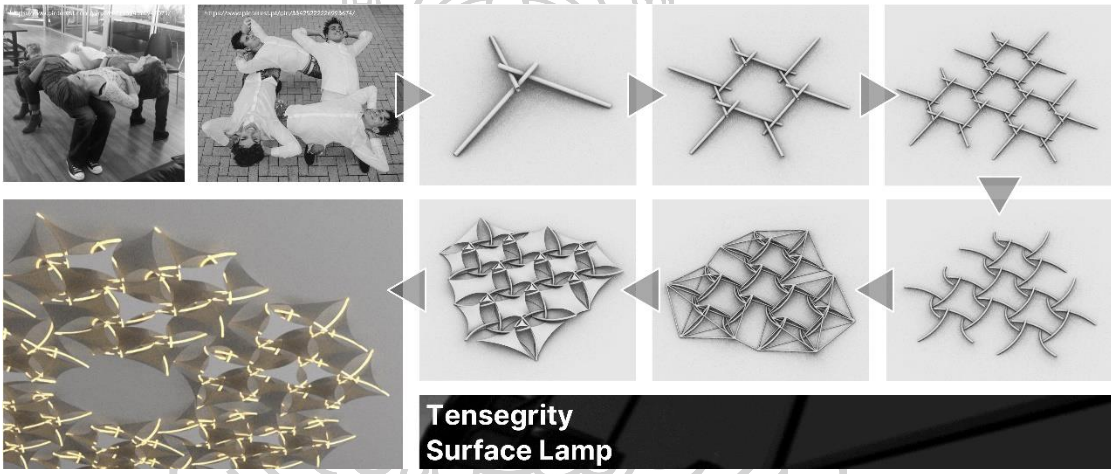


Figure 65 Concept framework of Tensegrity surface lamp

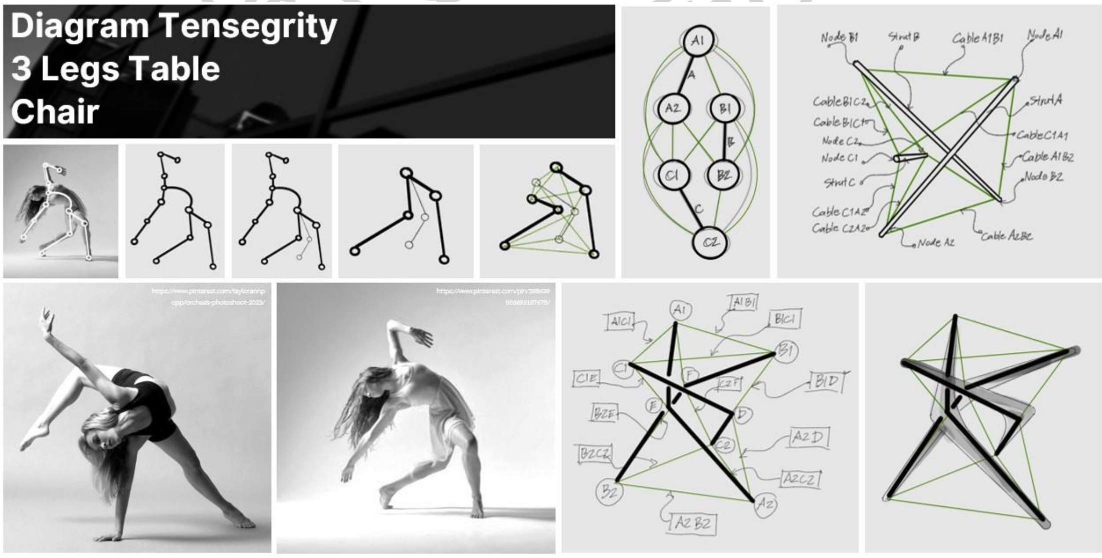


Figure 66 Concept framework of Tensegrity 3 Legs Table

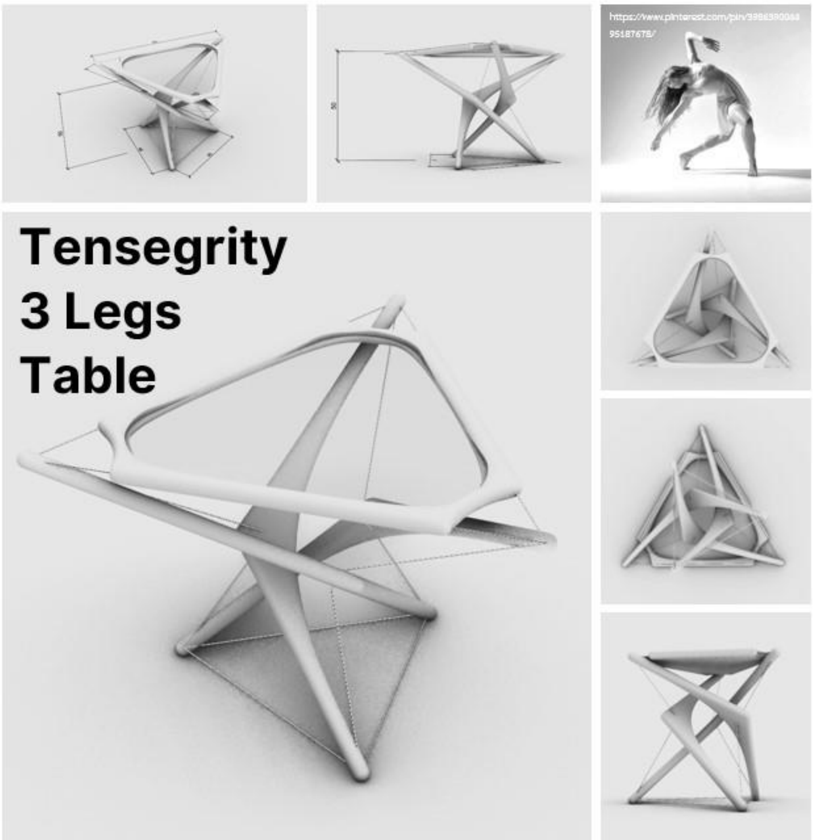


Figure 67 Tensegrity 3 Legs Table

Figure 68 Diagram of C2 - Tensegrity Furniture

3.3.5 Design Process in the 5th step: Experiment

Figure 69 Pieces of wood cut according to design for the top of the table.

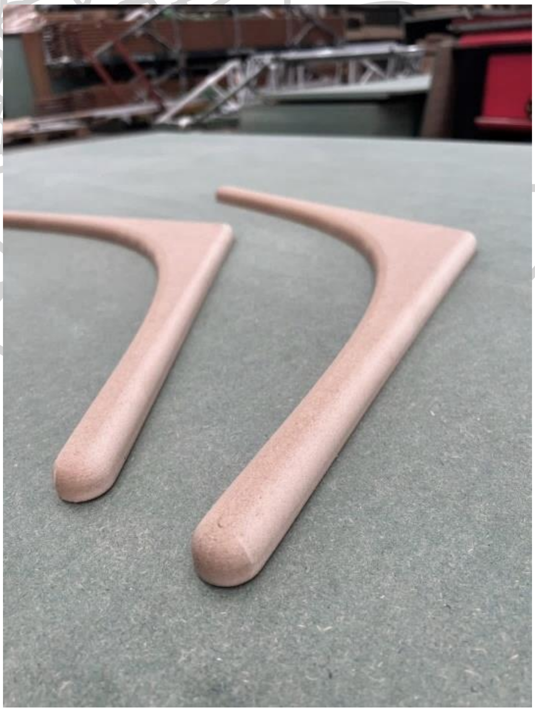


Figure 70 The wood is cut according to the design to make the top of the table and then glued together.

Figure 71 Apply glue to put the pieces of wood together.

Figure 72 Polish the wood for the next painting step.

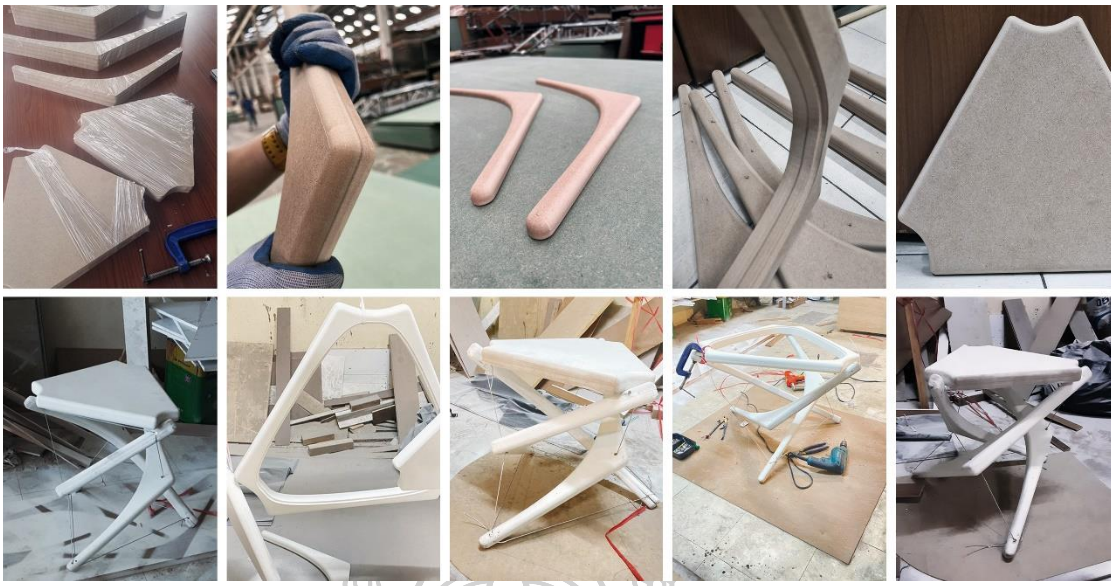


Figure 73 Process of production

3.3.6 Design Process in the 6th step: Production and Delivery

Figure 74 Furniture based on Tensegrity Structure Principle

3.4 Design Experiment

Design experiments can commence with either a physical simulation model or a computer simulation model. Experiments conducted using physical model simulations provide insights into the actual compressive and tensile forces, as well as the suitability and strength of the materials employed. On the other hand, experimenting with designs through computer simulation models offers the advantage of fostering more creative and innovative designs and shapes.

3.4.1 Experiment 1: Design Experimental: Architecture

Experiments were conducted with physical models, both small and 1:1 scale, to determine the shapes or patterns for connecting sub-elements in the units of the new tensegrity structure. The results showed that the model was able to fit its shape into a predetermined pattern, that the overall structure was strong and stable, and that the process for assembling the parts was simple, which made it easier to control the shape. The model also had the ability to add more units without completing the system, such as the tensegrity structure. Furthermore, the line system and the ability to cover the surface was similar to the dome system, in addition to the ability to change the shape of the structures.

The new tensegrity structure we investigated differs from the previous structures as it was designed using connecting subunits within a two-layer tensile surface structure. It is anticipated that this knowledge will enable the development of other forms of compression members and the creation of more diverse architectural and spatial designs. The structure can be formed by adding another layer on the surface of the compression-tensile dimension. This means that the model can withstand forces in any direction and thus serves as a key to the development of new tensegrity structure.

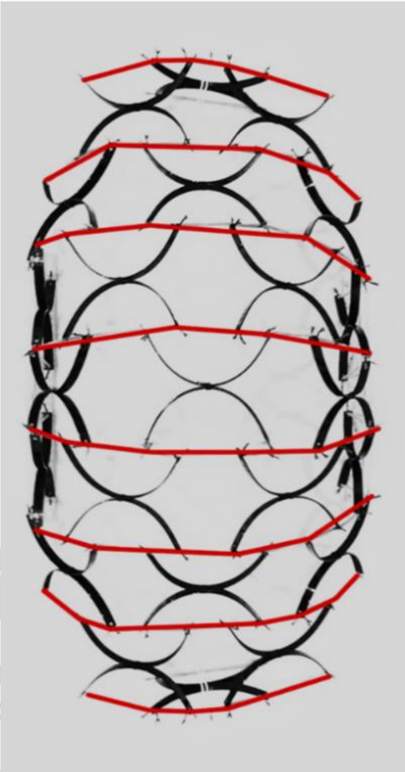


Figure 75 Experimenting the force of the structure

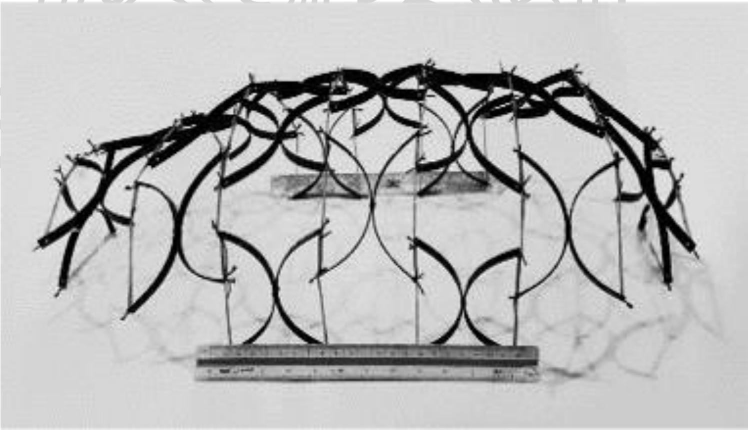


Figure 76 Experimenting the force of the structure

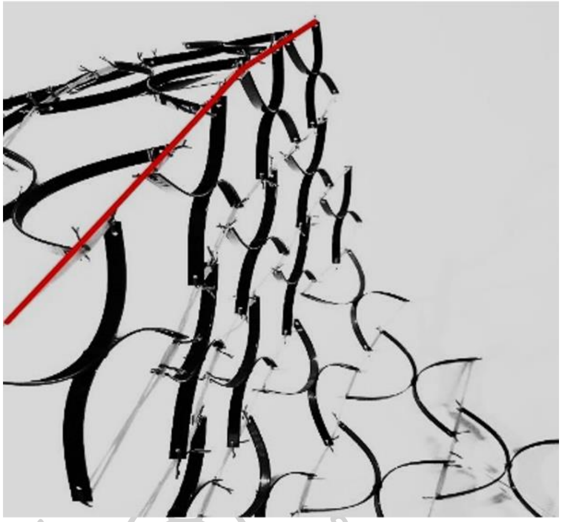


Figure 77 Experimenting the force of the structure

Figure 78 Experiment to Connect the Subunits within a Two-Layer Tensile Surface Structure

Figure 79 Experiment to Connect the Subunits within a Two-Layer Tensile Surface Structure

Figure 80 Double-layer Tensegrity structure model

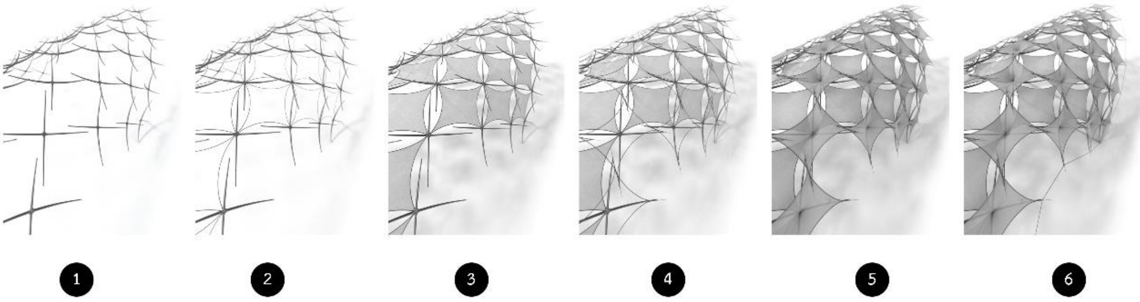


Figure 81 Process of Double-layer Tensegrity structure model

The structure can be formed by adding another layer to the surface of the compression-tensile dimension. This means the model can withstand forces in every direction, thereby serving as the key to developing new tensegrity structure.

Figure 82 Double-layer Tensegrity structure model

Figure 83 Experimenting with a Full-Scale Physical Model of Tensegrity Structure

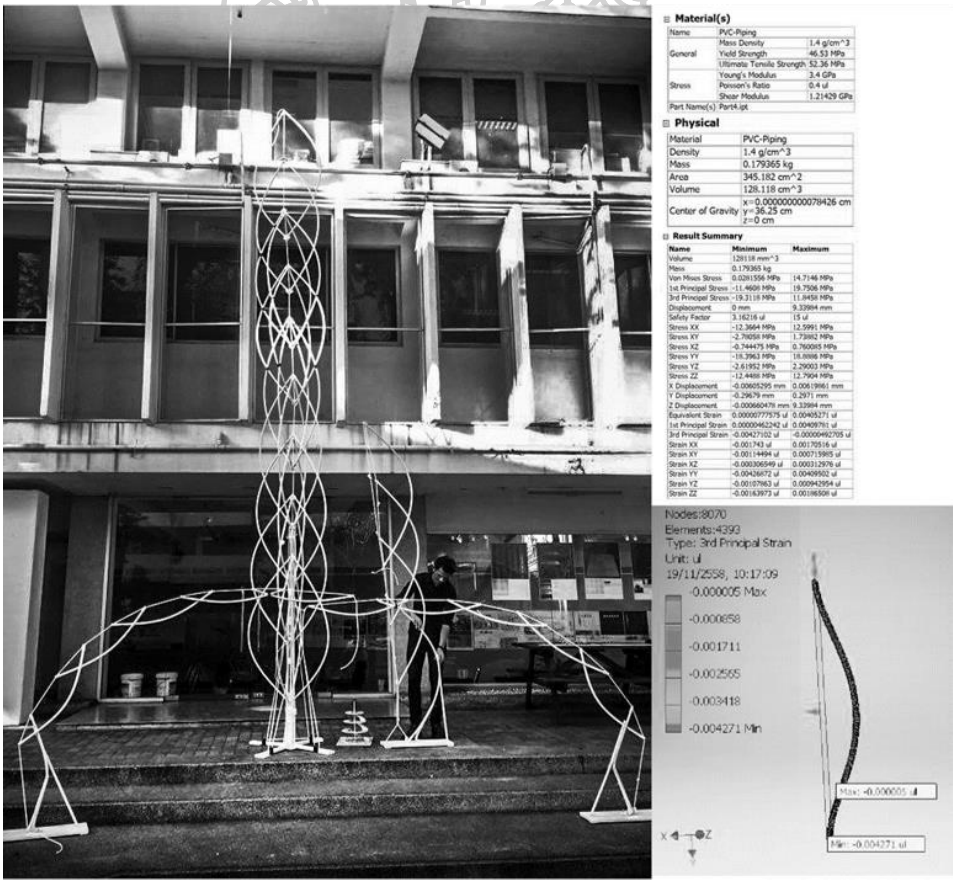


Figure 84 Experimenting with a Full-Scale Physical Model of Tensegrity Structure

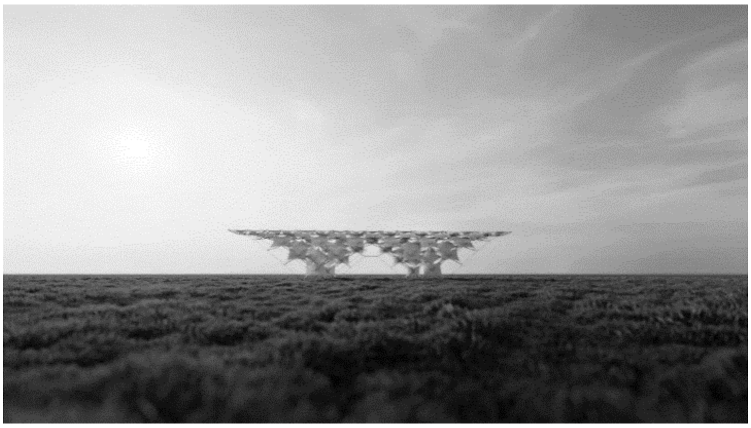


Figure 85 Final Mixed Tensegrity Structure Model

Figure 86 Final Mixed Tensegrity Structure Model

Figure 87 Double-layer Tensegrity structure model

Figure 88 Double-layer Tensegrity structure model

Figure 89 Models for simulating other forms of Tensegrity structures

Figure 90 Models for simulating other forms of Tensegrity structures

3.4.2 Experiment 2: Design Experimental from The Spine Tensegrity concept

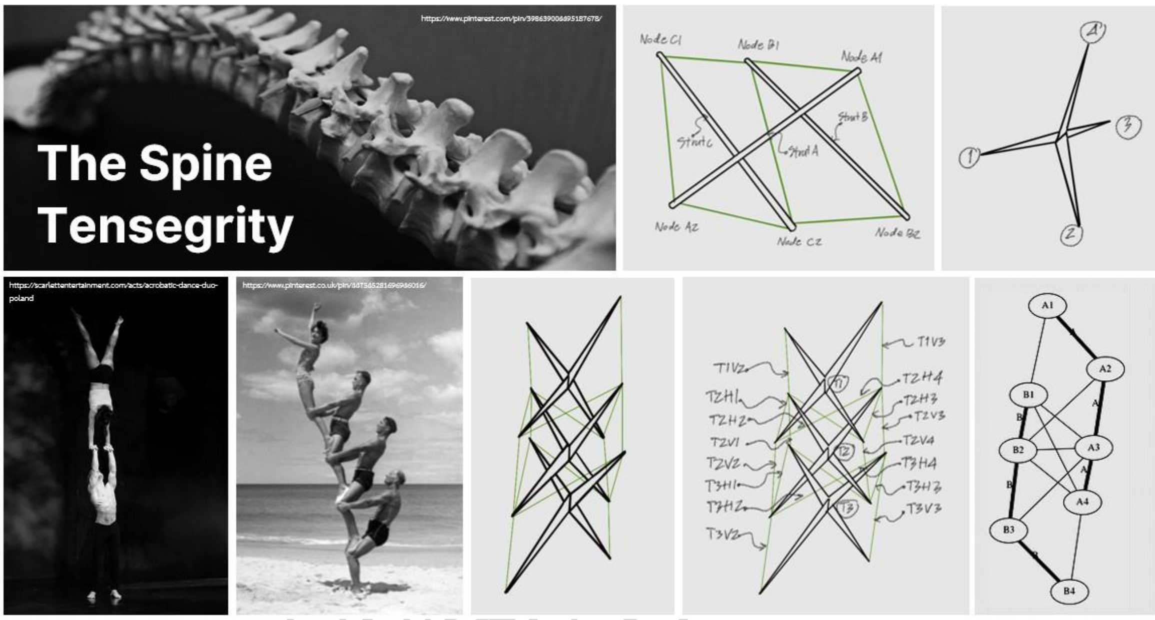


Figure 91 The Spine Tensegrity concept

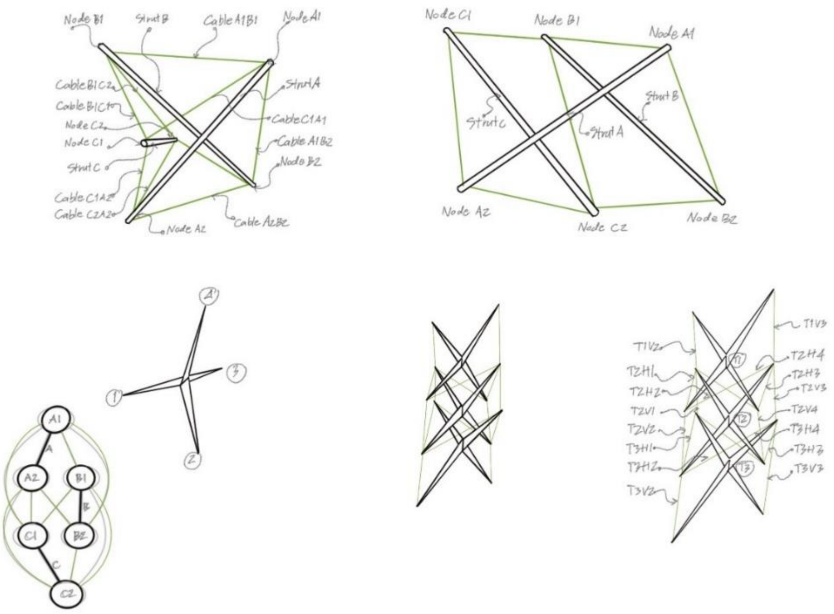


Figure 92 The Spine Tensegrity Sketch

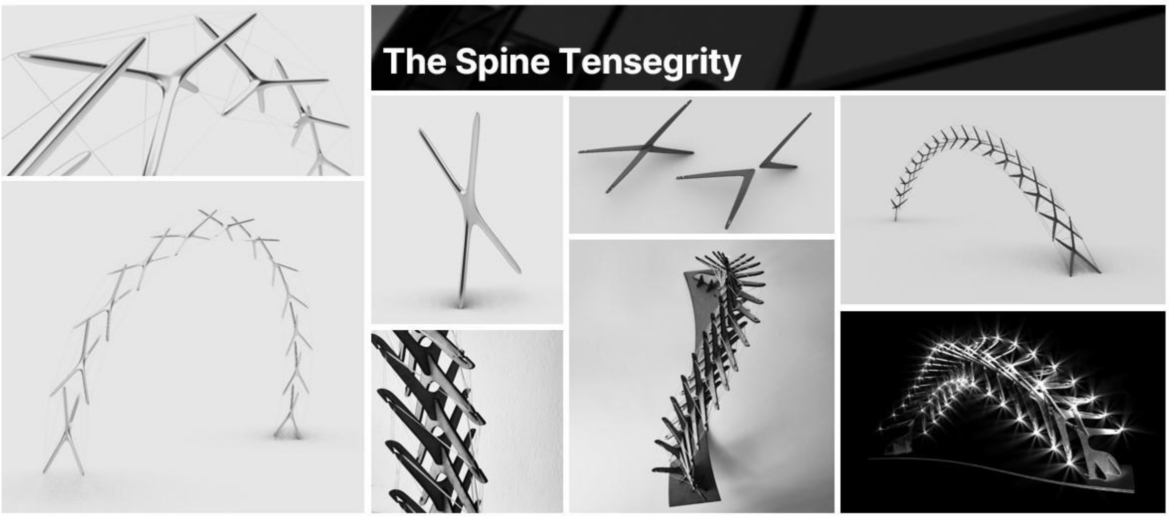


Figure 93 The spine Tensegrity concept

Figure 94 The spine Tensegrity

Figure 95 The spine Tensegrity

Figure 96 The spine Tensegrity

Figure 97 Molecular Structure for Sculpture

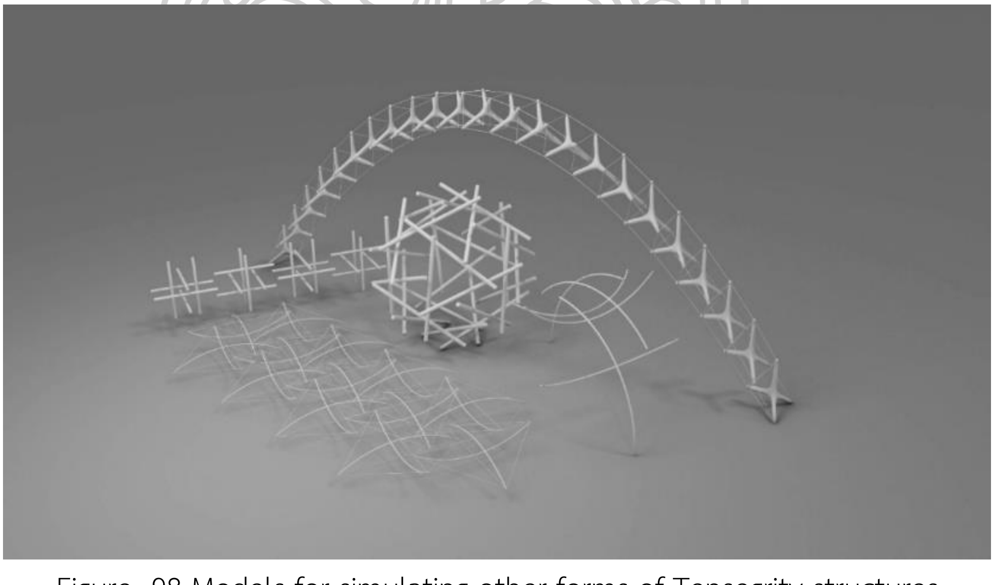


Figure 98 Models for simulating other forms of Tensegrity structures

3.4.3 Experiment 3: Design Experimental from Twist tensegrity

Figure 99 Twist tensegrity lamp concept

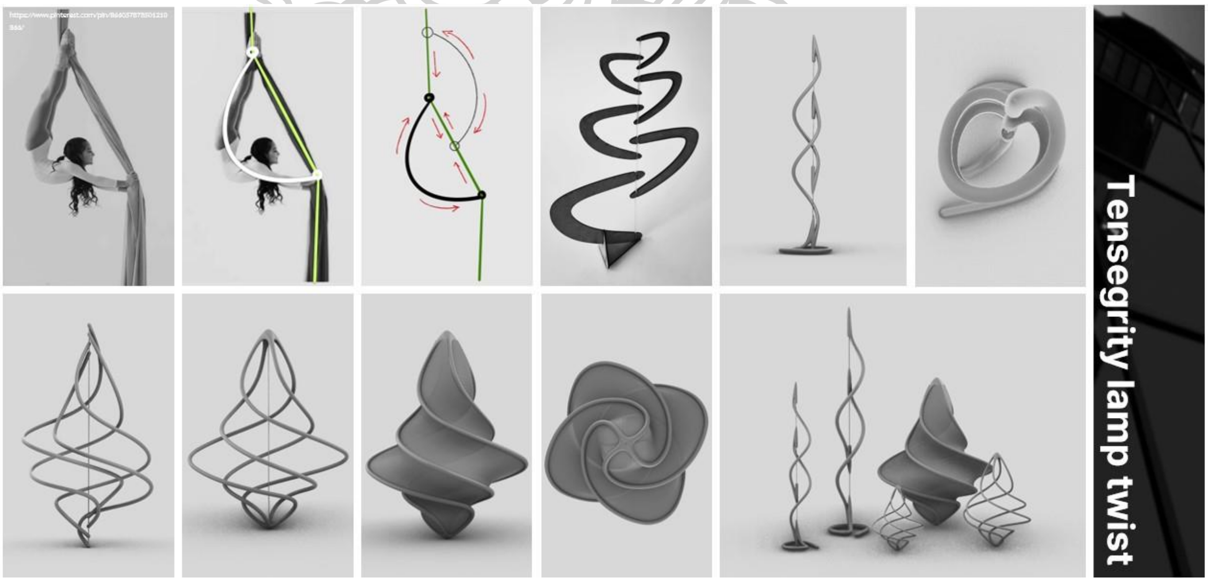


Figure 100 Twist tensegrity lamp

Figure 101 Twist Tensegrity lamp

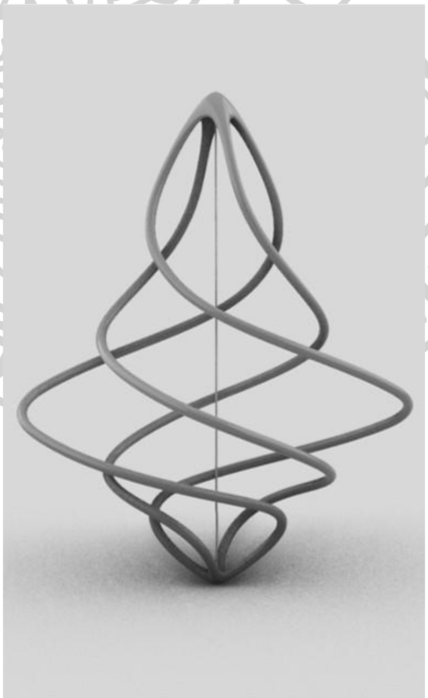


Figure 102 Twist Tensegrity lamp

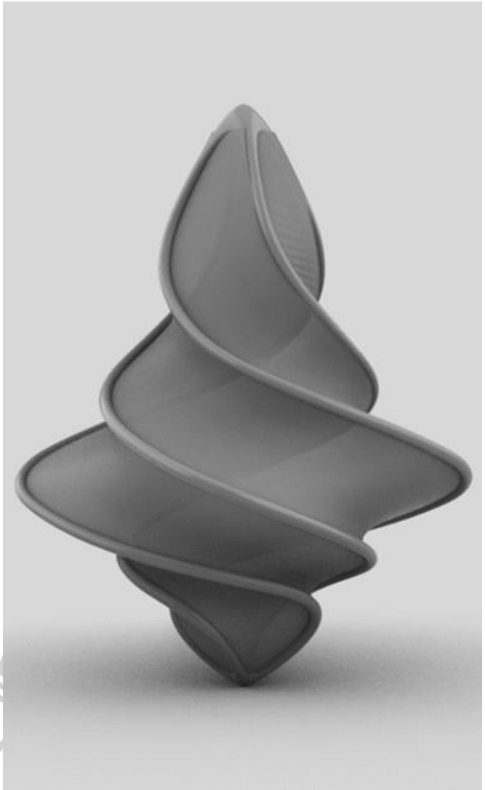


Figure 103 Twist Tensegrity lamp

Figure 104 Tensegrity

3.4.4 Experiment 4: Design Experimental of Anatomy of Tensegrity lamp

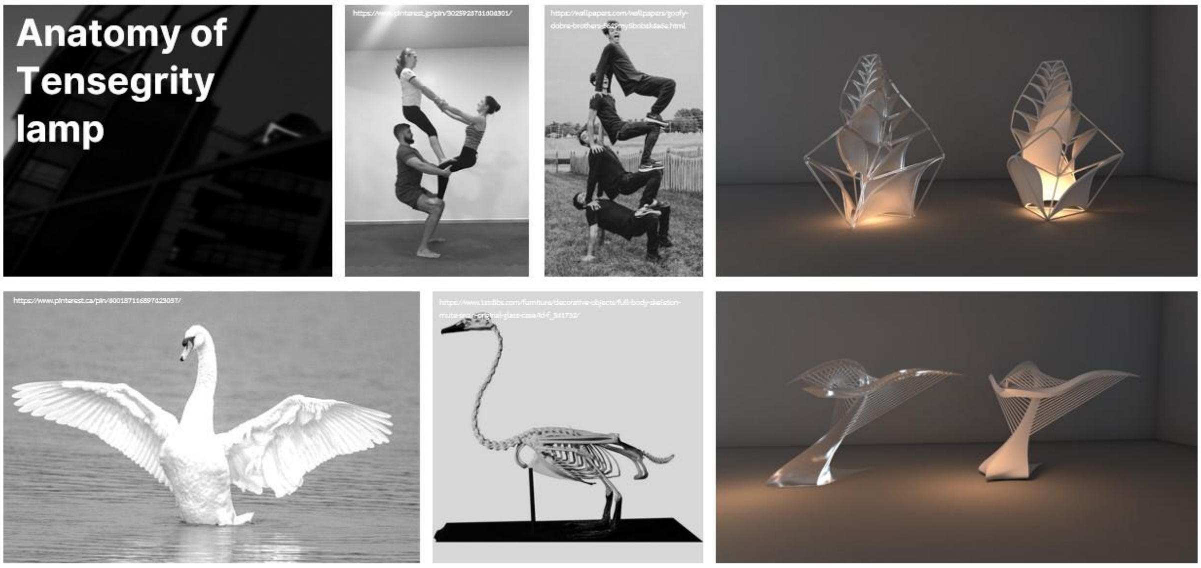


Figure 105 Tensegrity Sculpture

3.4.5 Experiment 5: Design Experimental from Tensegrity Surface lamp

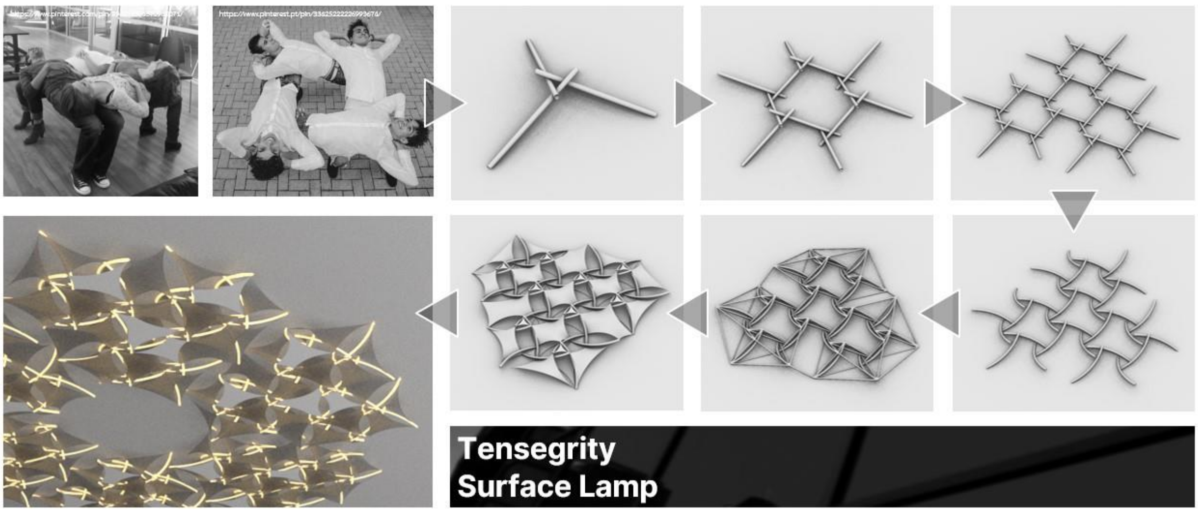


Figure 106 Tensegrity lamp

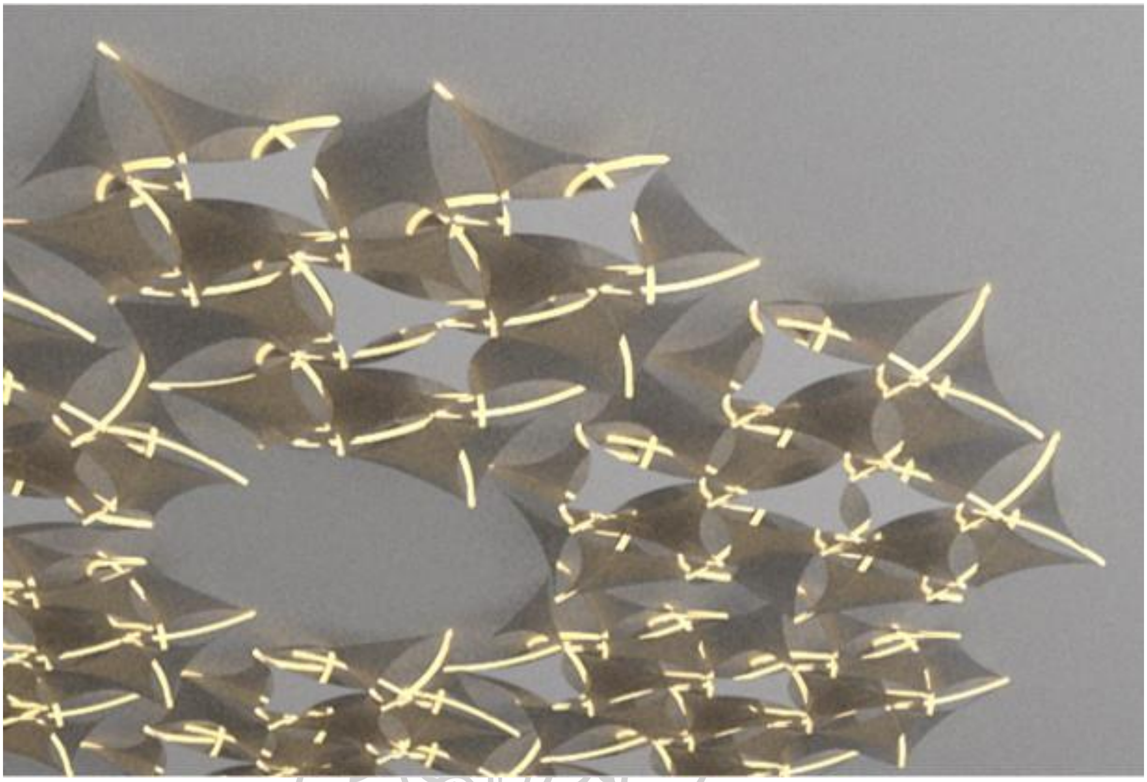


Figure 107 Tensegrity lamp with decorate celling in interior design

3.4.6 Experiment 6: Design Experimental Molecular Structure Concept

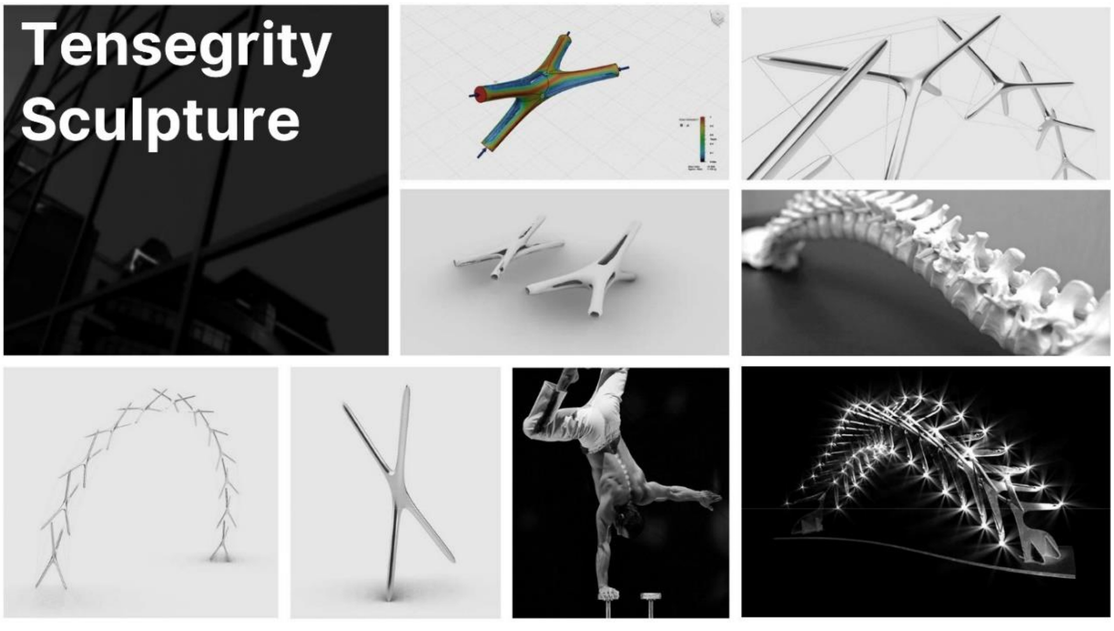


Figure 108 Molecular Structure concept

Figure 109 Molecular Structure for Sculpture

3.4.7 Experiment 7: Molecular structure system: Toys part

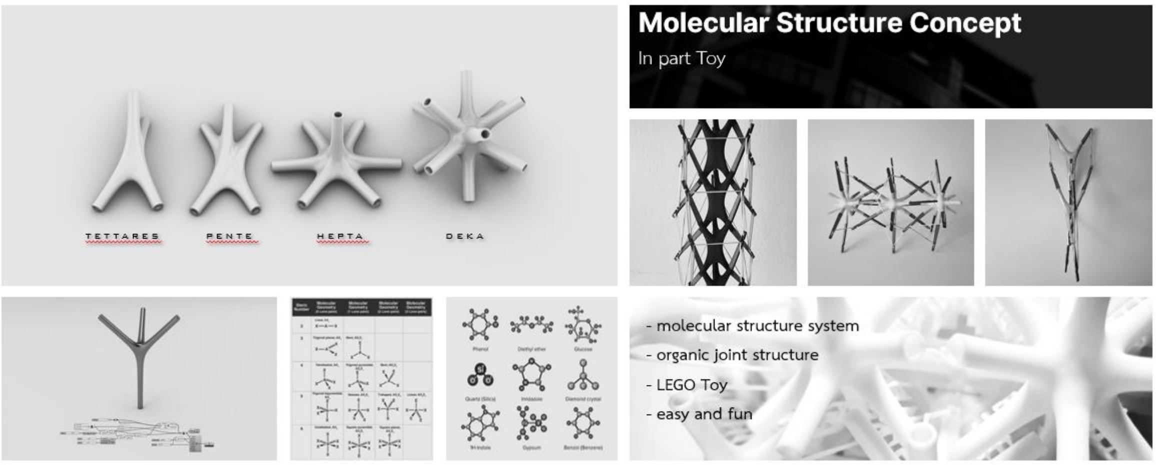


Figure 110 Molecular structure system in Toys part

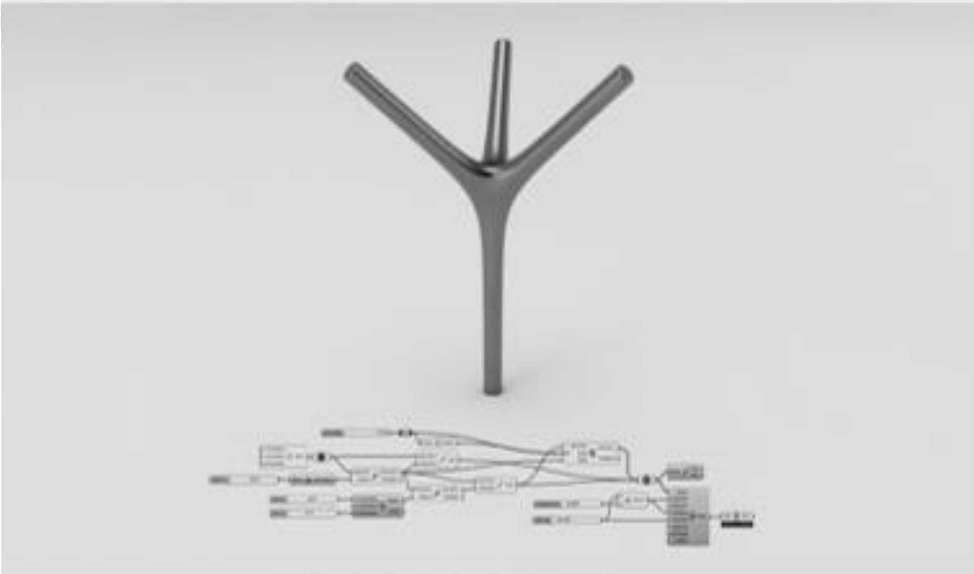


Figure 111 Molecular structure system in Toys part

Figure 112Molecular structure system in Toys part

3.4.8 Experiment 8: Design Experimental from Tensegrity Balance concept

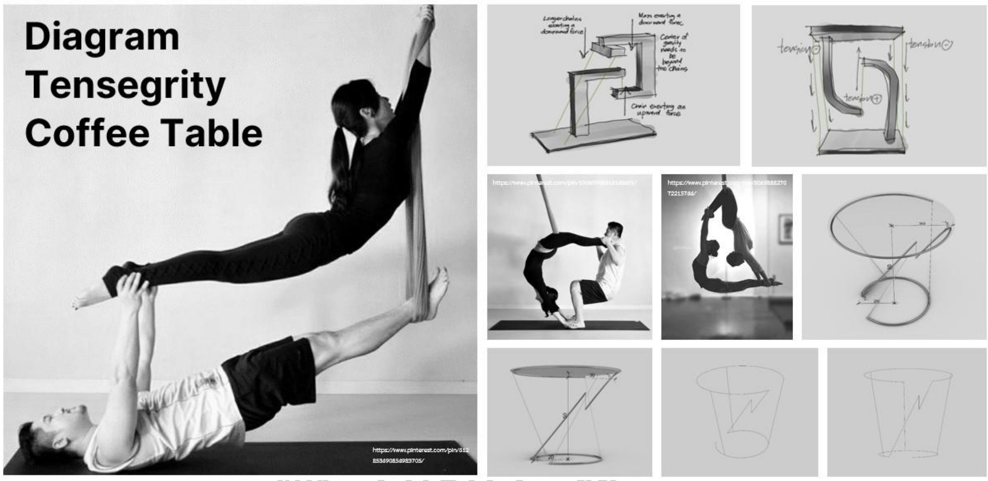


Figure 113 Diagram Tensegrity coffee table

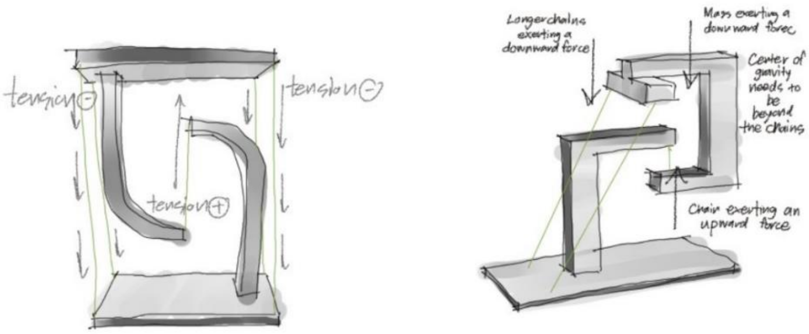


Figure 114 Tensegrity idea Sketch

Figure 115 Tensegrity Coffee Table Model

Figure 116 Tensegrity Coffee Table Model

Figure 146 Tensegrity coffee Table

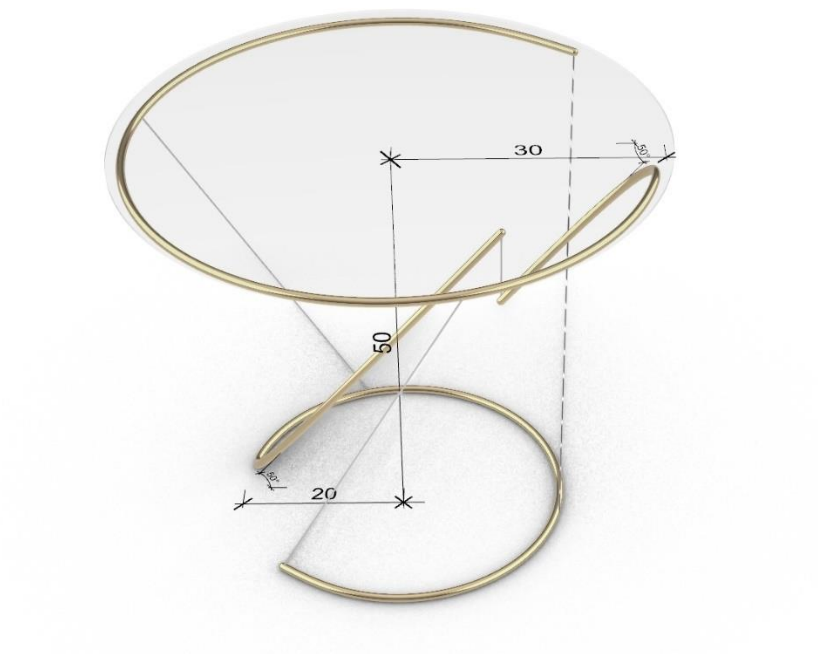


Figure 147 Tensegrity coffee Table

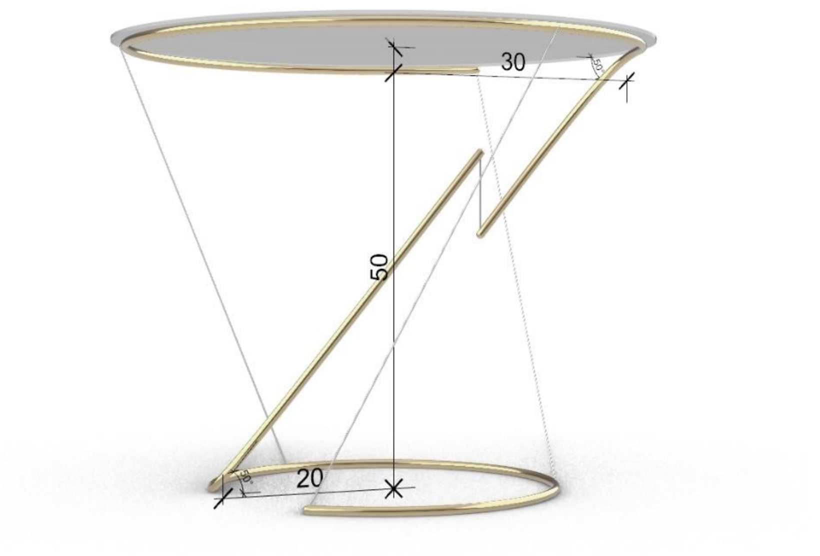


Figure 148 Tensegrity coffee Table

Figure 117 Making a side table frame using wrought iron

Figure 118 Steps for painting the table frame

3.4.9 Experiment 9: Design Experimental for 3 Legs Table and Chairs set

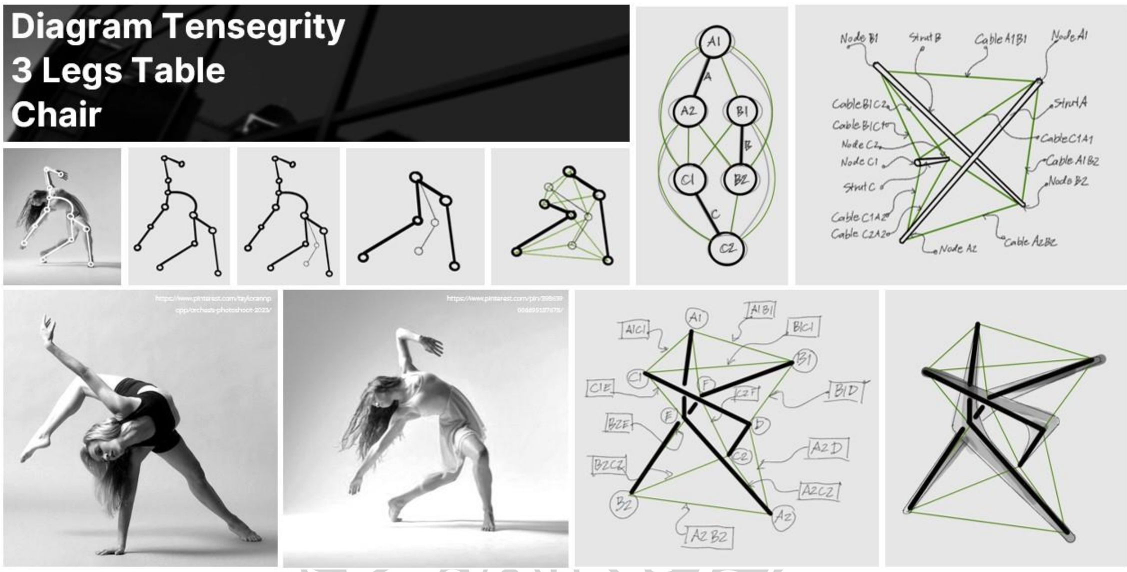


Figure 119 Diagram of Tensegrity 3 Legs Table Chair

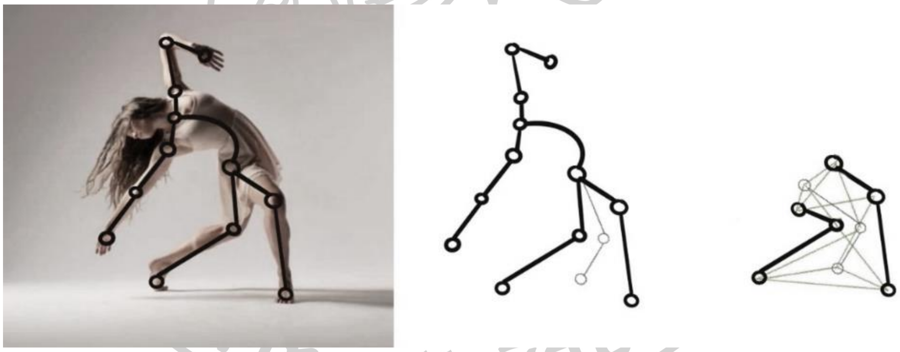


Figure 120 Diagram of Tensegrity 3 Legs Table Chair Concept

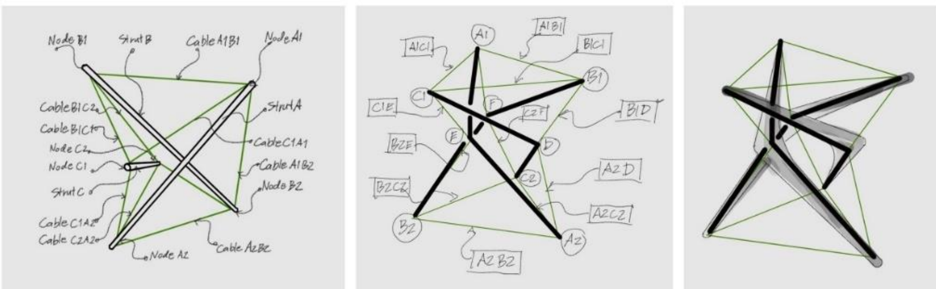


Figure 121 Diagram of Tensegrity 3 Legs Table Chair Sketch

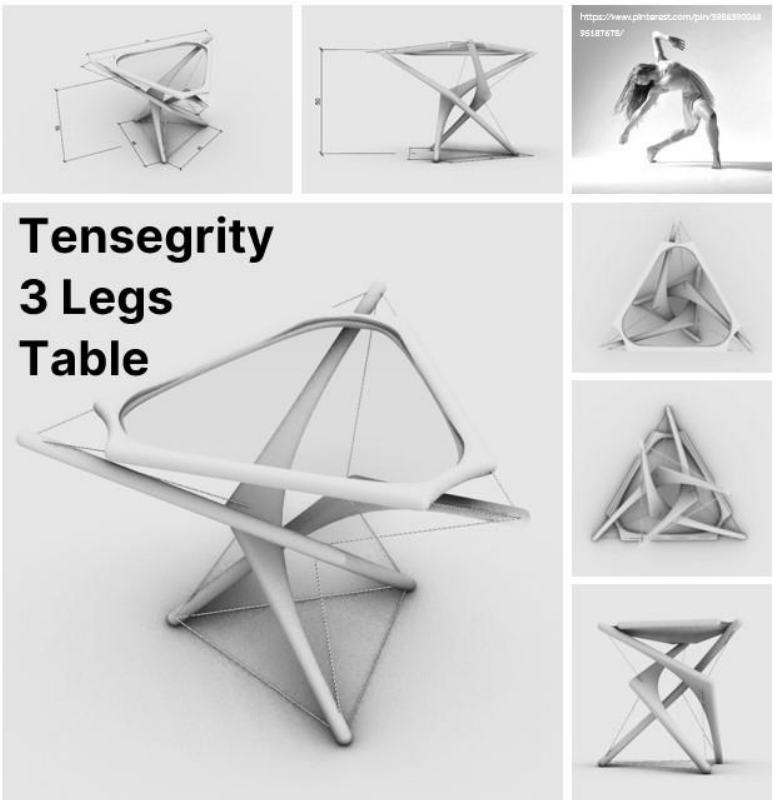


Figure 122 Tensegrity 3 Legs Table

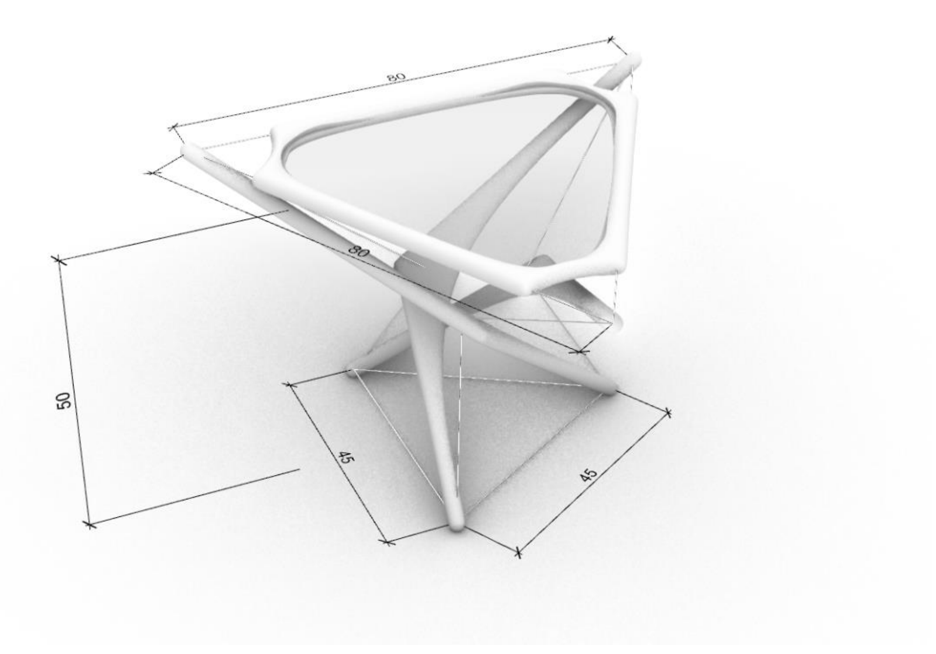


Figure 123 Tensegrity 3 Legs Table

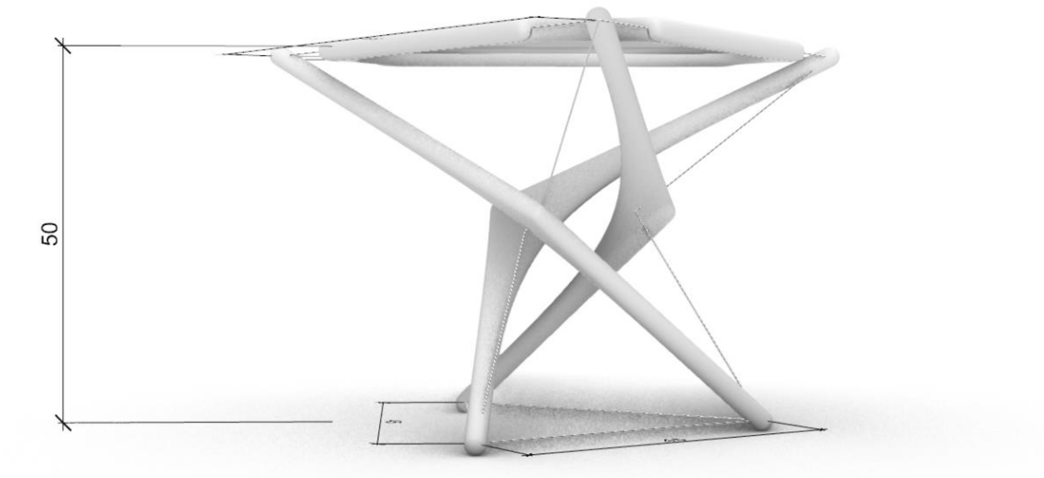


Figure 124 Tensegrity 3 Legs Table

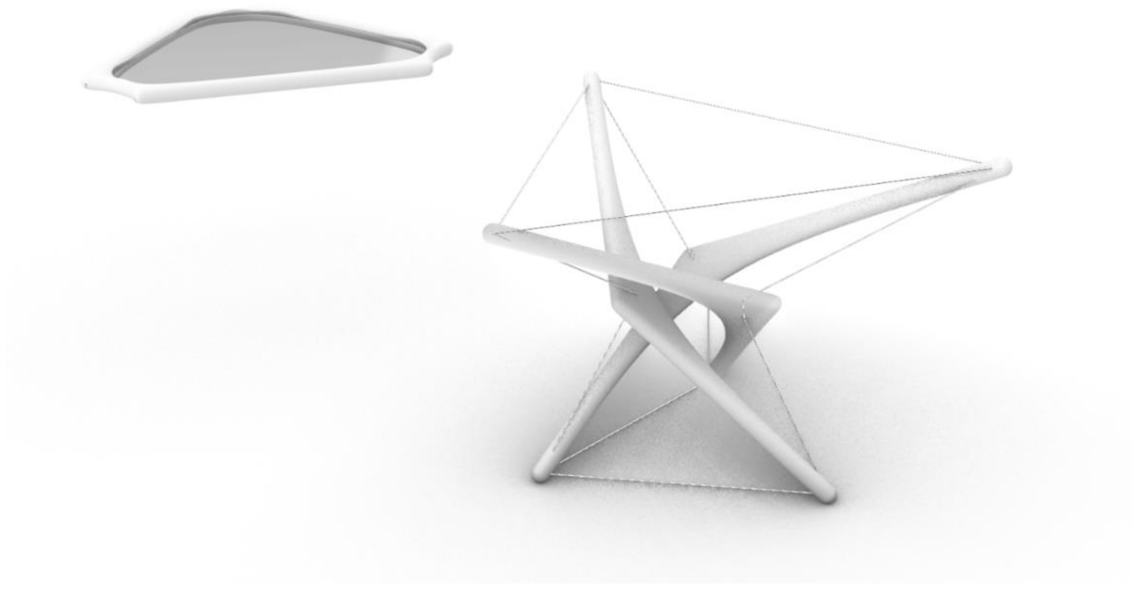


Figure 125 Tensegrity 3 Legs Table

Figure 126 Complete assembly and proceed to the polishing and painting process.

Figure 127 Complete assembly and proceed to the polishing and painting process.

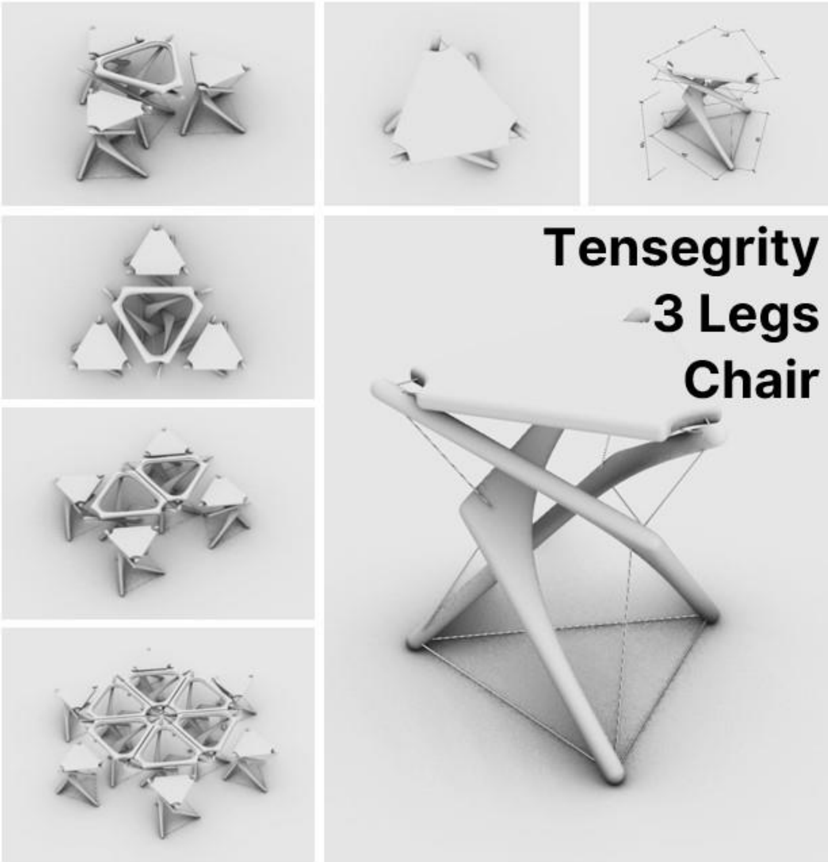


Figure 128 Tensegrity 3 Legged Chairs

Figure 129 Tensegrity 3 Legged Chairs

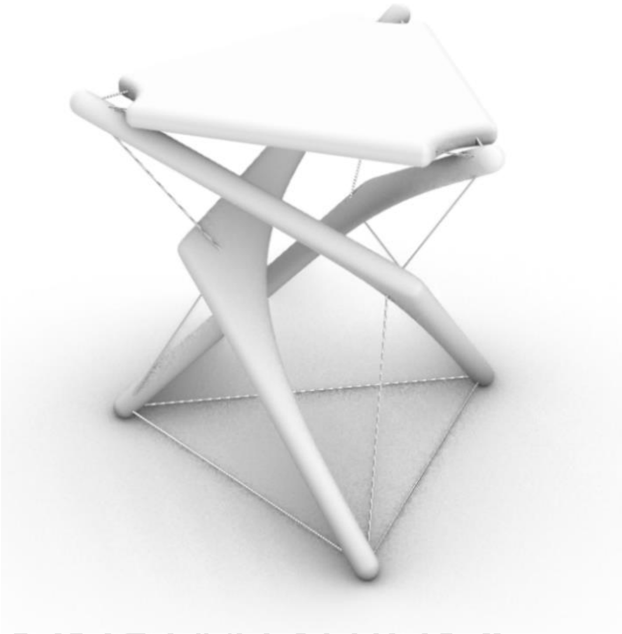


Figure 130 Tensegrity 3 Legged Chairs

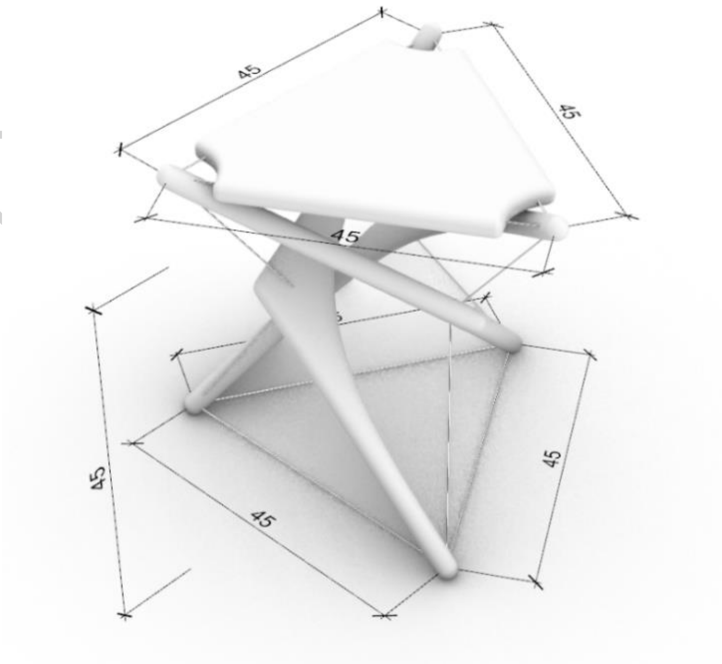


Figure 131 Tensegrity 3 Legged Chairs

Figure 132 Pieces of wood cut according to design for the top of the table.

Figure 133 The wood is cut according to the design to make the top of the table and then glued together.

Figure 134 Apply glue to put the pieces of wood together.

Figure 135 Polish the wood for the next painting step.

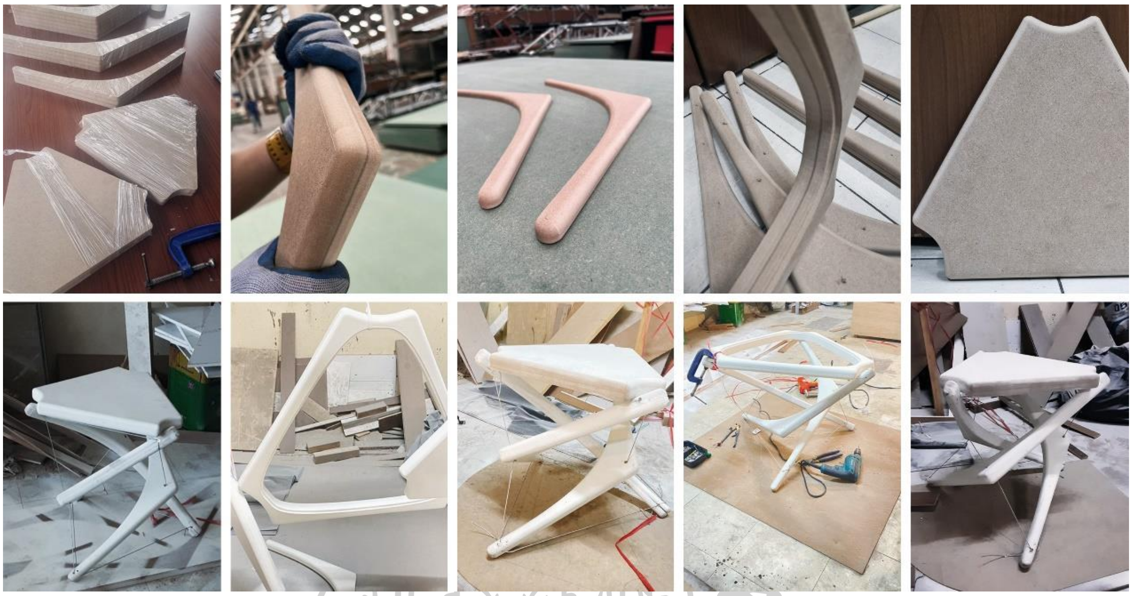


Figure 136 Process of production

3.4.10 Experiment 10: Design Experimental for C-Tensegrity

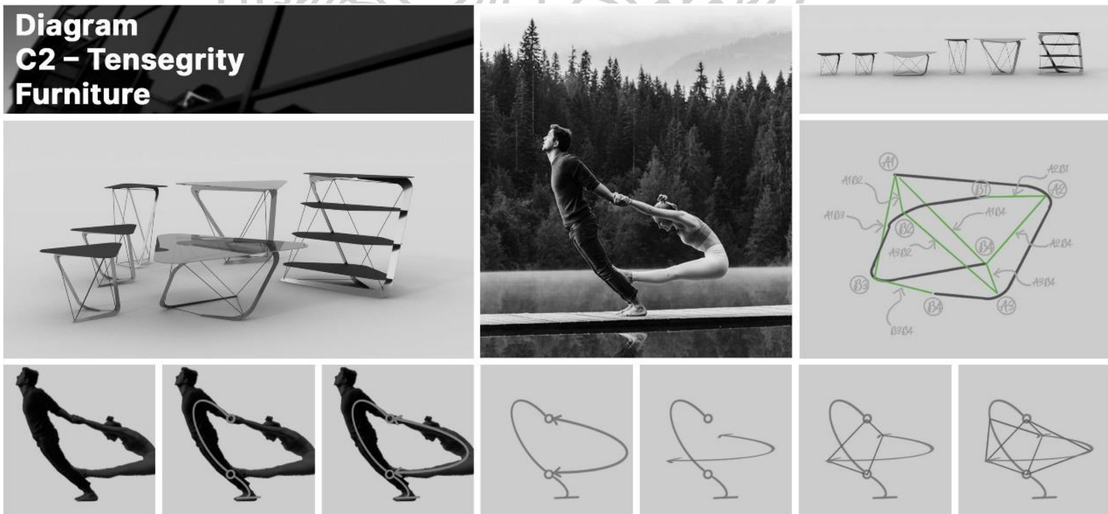


Figure 137 Diagram of C2 - Tensegrity Furniture

Figure 138 Computer simulation of furniture models

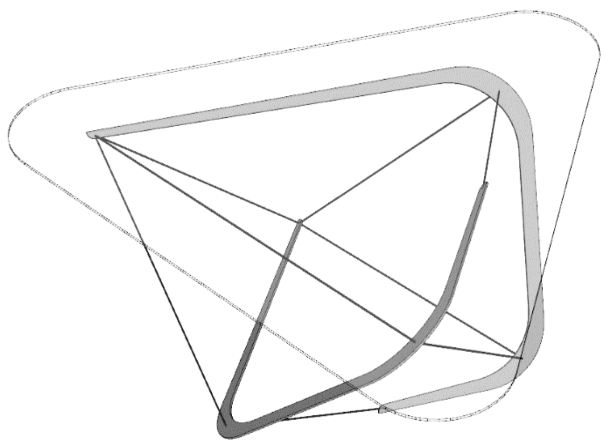


Figure 139 Computer simulation of furniture models

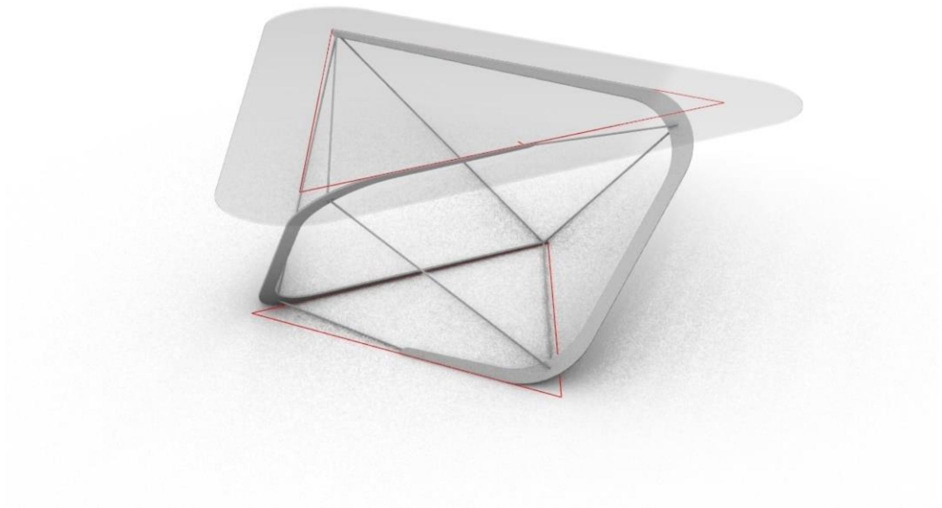


Figure 140 Computer simulation of furniture models

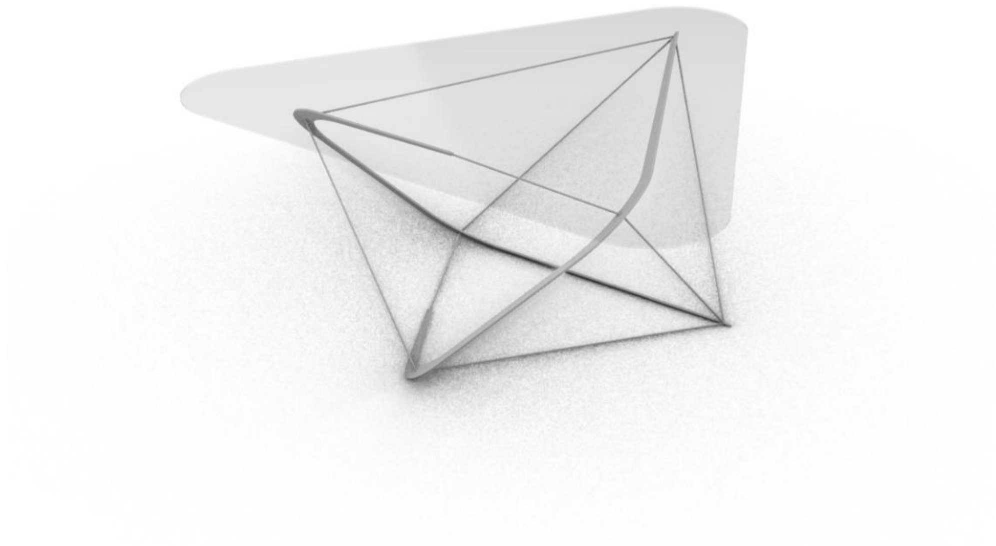


Figure 141 Computer simulation of furniture models

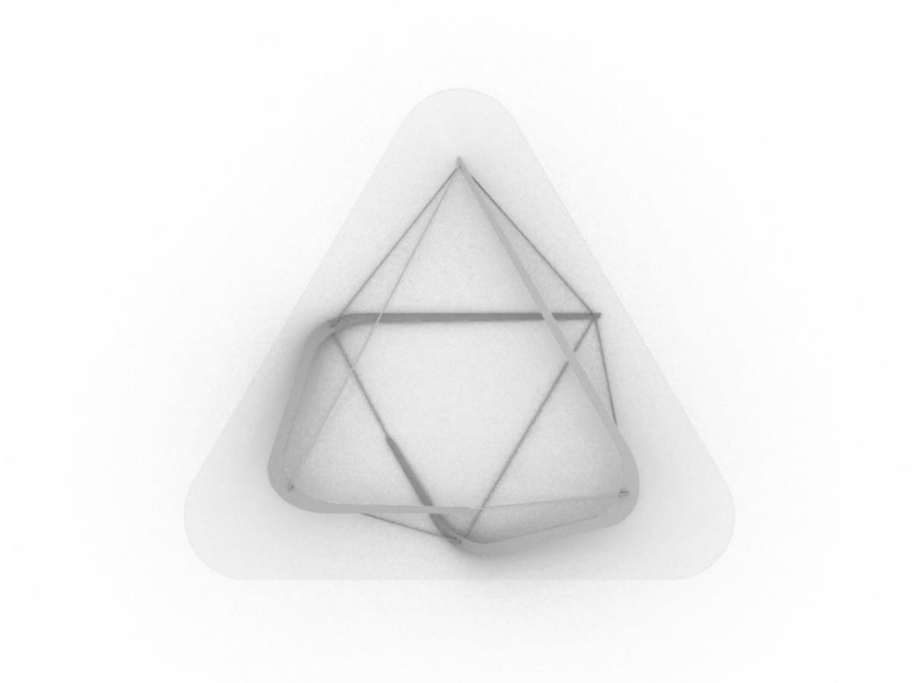


Figure 142 Computer simulation of furniture models

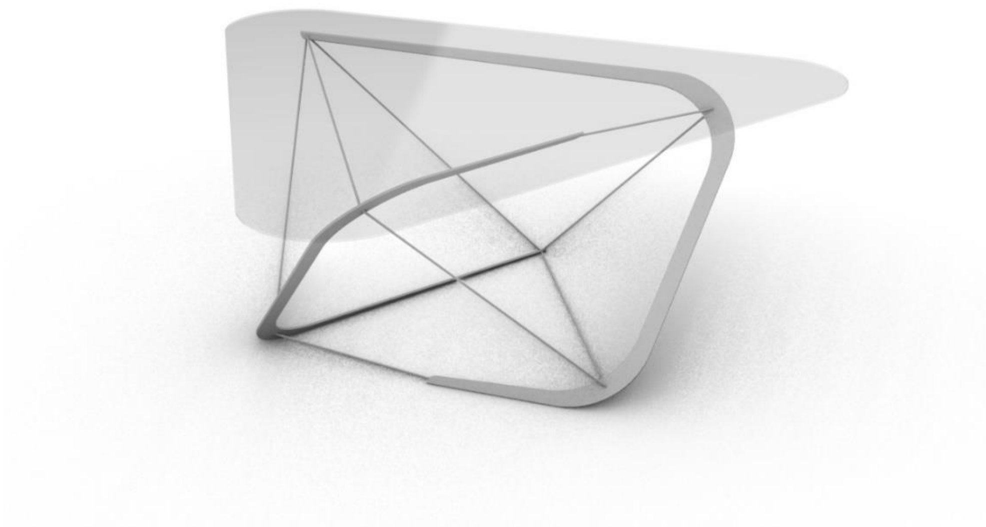


Figure 143 Computer simulation of furniture models

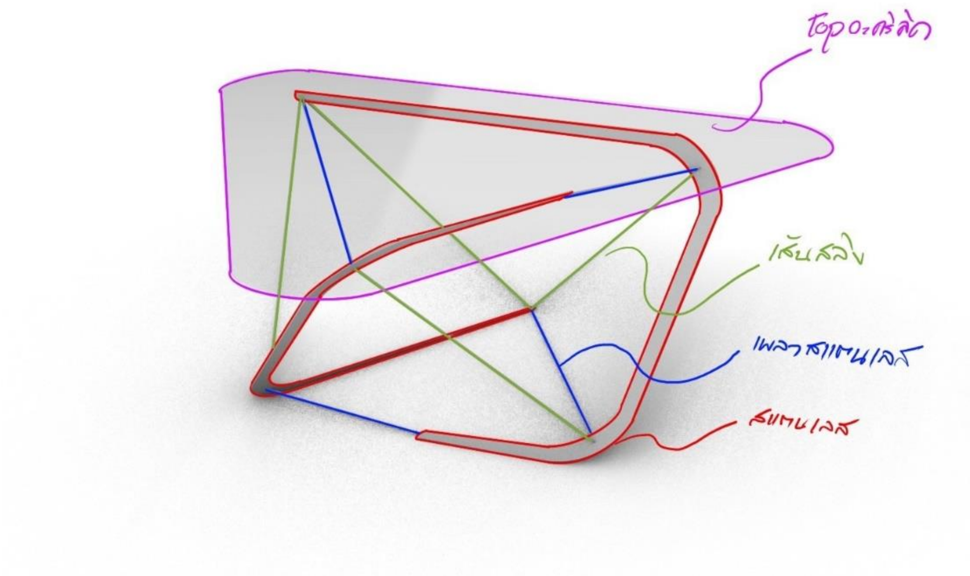


Figure 144 Set the direction for stretching ropes and various materials.

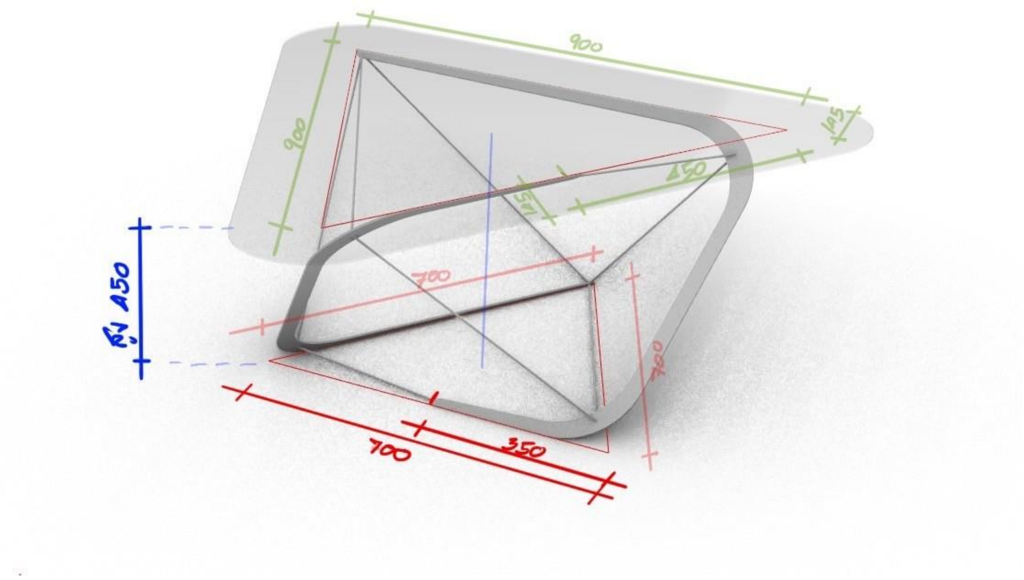


Figure 145 Specify size and proportion

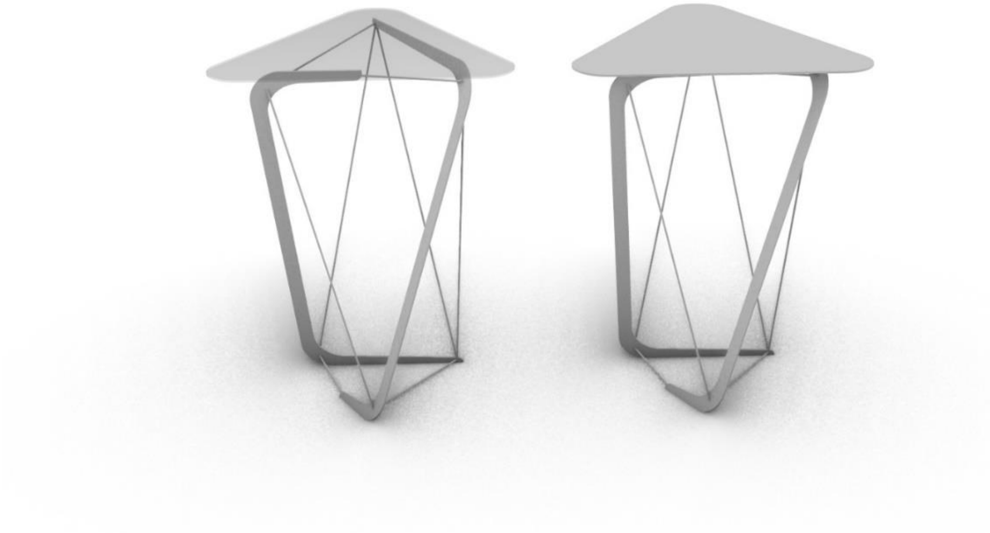


Figure 146 Computer simulation of furniture models

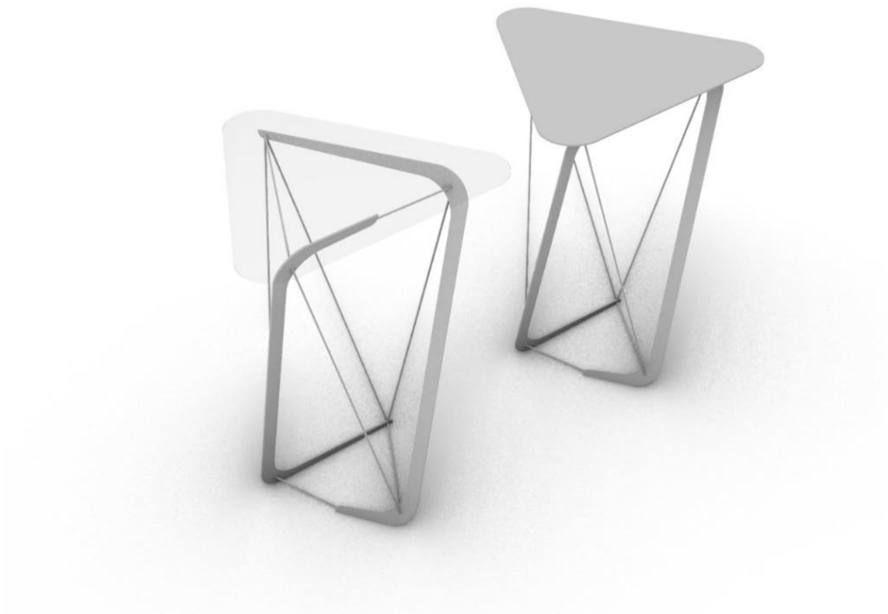


Figure 147 Computer simulation of furniture models

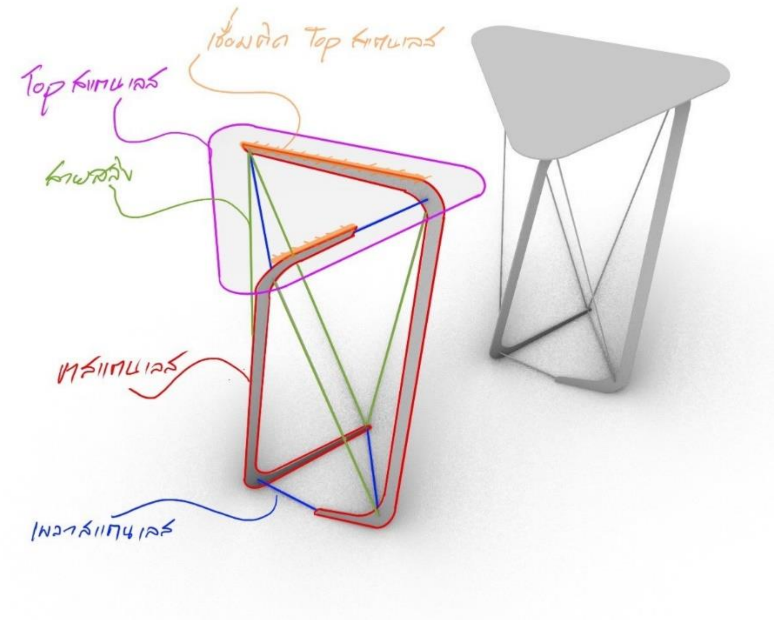


Figure 148 Set the direction for stretching ropes and various materials.

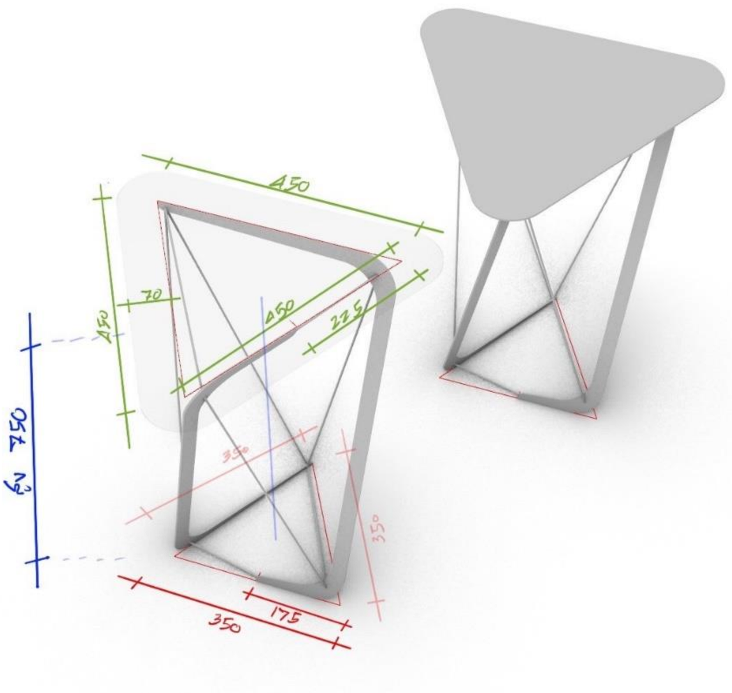


Figure 149 Specify size and proportion

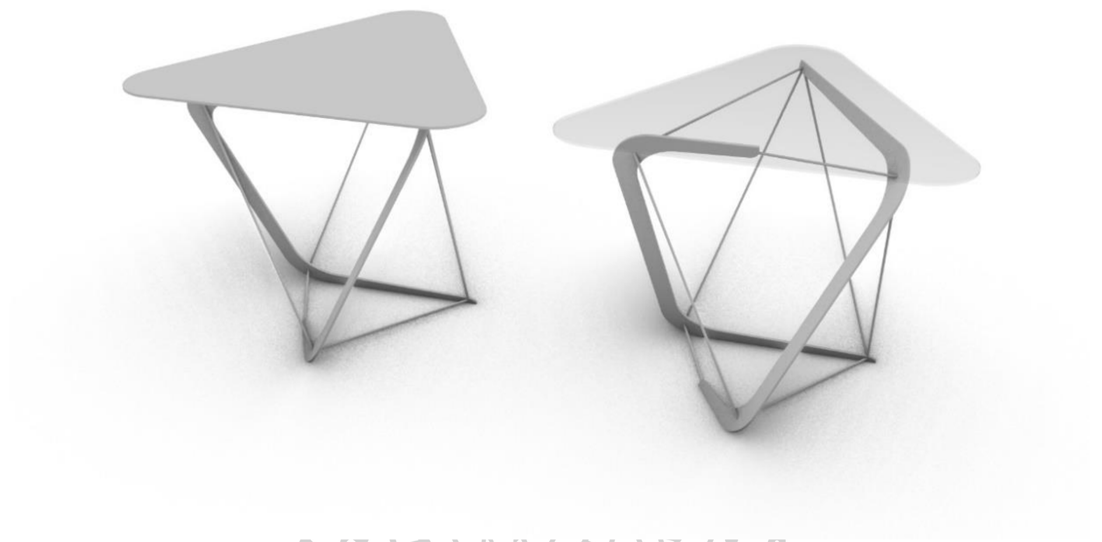


Figure 150 Computer simulation of furniture models

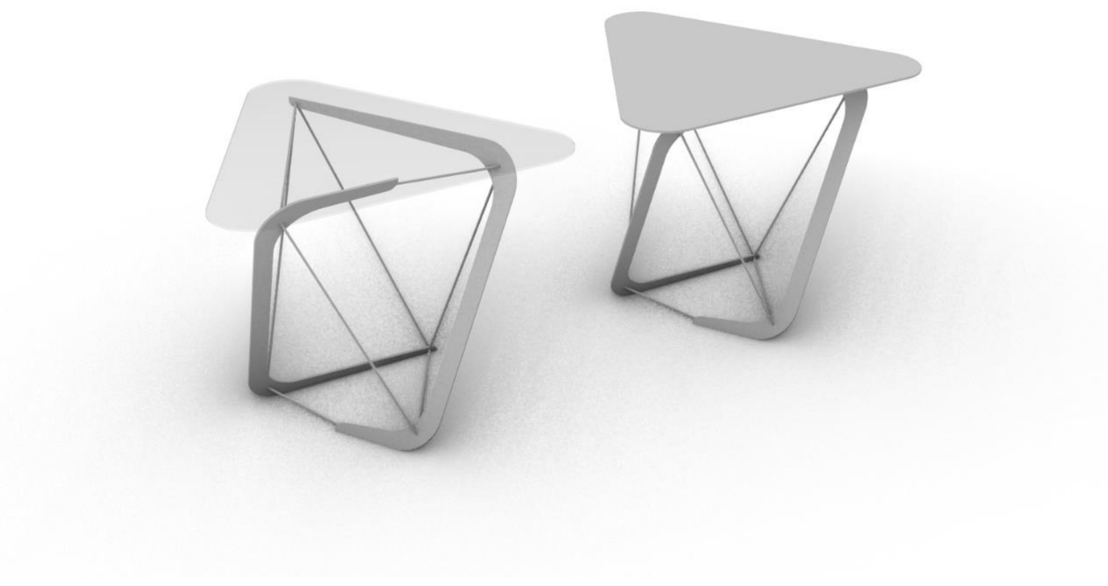


Figure 151 Computer simulation of furniture models

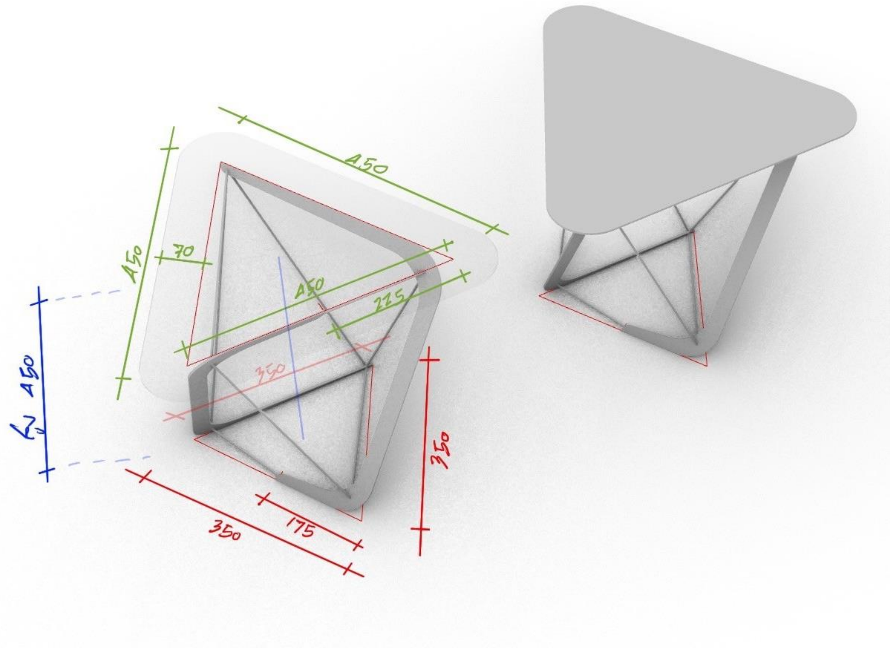


Figure 152 Specify size and proportion

Figure 153 Make a small physical model.

Figure 154 Make a small physical model.

Figure 155 Make a small physical model.

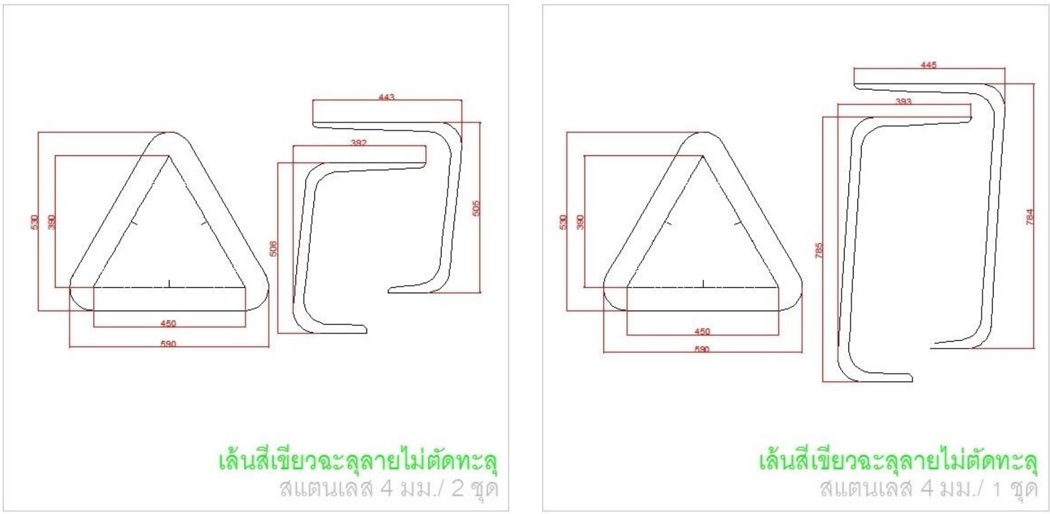


Figure 156 Technical drawings for sending data to cut stainless steel.

Figure 157 A physical model for assembling a furniture frame.

Figure 158 A physical model for assembling a furniture frame.

Figure 159 The physical model is mounted on the top of the furniture.

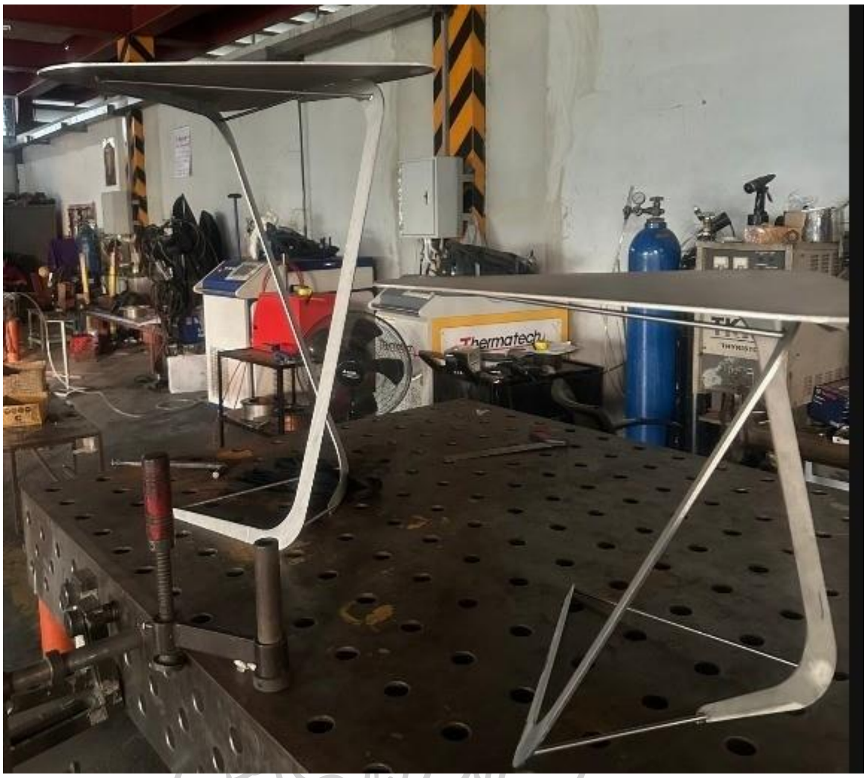


Figure 160 The physical model is mounted on the top of the furniture.

Figure 161 Sling material number 3

Figure 162 Connection of sling equipment

Figure 163 Connection of sling equipment

Figure 164 Set the sling connection point with tape.

Figure 165 Set the sling connection point with tape.

Figure 166 Set the sling connection point with tape.

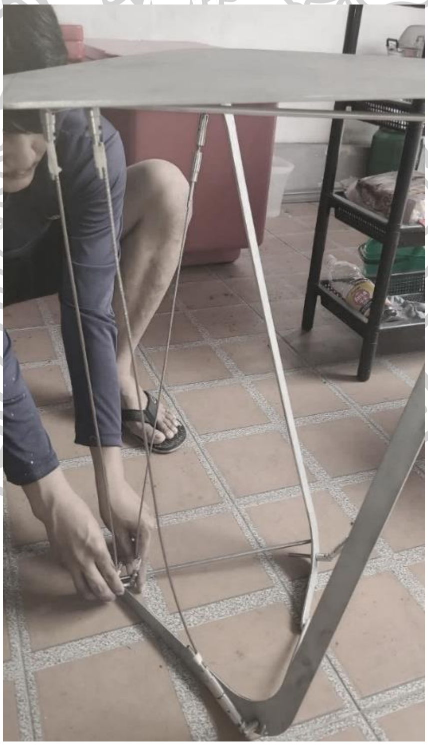


Figure 167 Steps for stretching the sling

Figure 168 Precisely gauge the water level to ensure that the top of the furniture is positioned accurately at a level of 0 degrees.

Figure 169 Precisely gauge the water level to ensure that the top of the furniture is positioned accurately at a level of 0 degrees.

Figure 170 Steps for stretching the sling

Figure 171 Steps for stretching the sling

Figure 172 Complete assembly and proceed to the polishing and painting process.

Figure 173 Coloring process

Chapter 4

Research Results

The new tensegrity structure having examined differs from previous structures in that it is composed of connecting subunits within a two-layer, tensile surface structure. It is expected that this knowledge will enable the development of other compression part shapes and the creation of more diverse architectural and spatial designs. The structure can be formed by adding another layer on top of the compression-tensile dimension. This means that the model can withstand forces in any direction and thus serves as a key to the development of new tensegrity structure.

4.1 Structure

4.1.1 New Tensegrity Structure Design, Double-layer Tensegrity structure

This research aims to focus on the design of content structure development. Tensegrity should be used in the architecture and maximize the potential of the properties of structure. The content classification of Tensegrity can be organized into three types of Tensegrities: 1. Dome system 2. Linear system 3. Self-replicating system. When analyzing the properties of the three Tensegrity systems. Some tensegrity structures had good coverage. At the same time, some systems can change or control the expansion of the overall shape of the structure. However, when classifying the 3 Tensegrity Structural Systems classification, there is still a limitation when it comes to using them as structures that can change spaces in size or shape. When considering the Tensegrity structure system that can cover the area or form a building shell structure, it was found that only the Tensegrity structure, the dome system, has limitations in the shape that cannot be changed in other ways. round shape. Although the tensegrity of the self-replicating tensegrity can cover and reshape the area, the said capabilities of the tensegrity are not effective in terms of ground coverage and completely deformed.

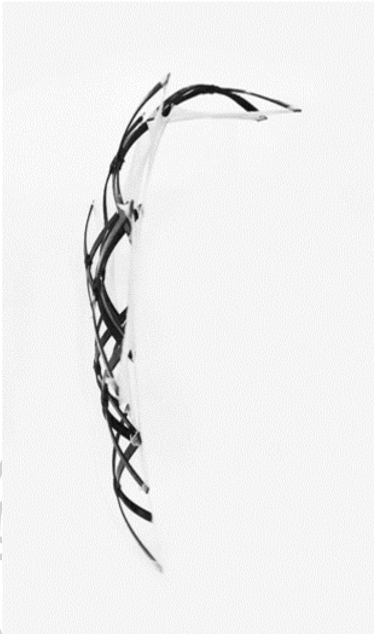


Figure 174 Force Pattern of Pre-Existing Tensegrity Structure

Figure 175 Experiment to Connect the Subunits within a Two-Layer Tensile Surface

From the analysis of the data of the Tensegrity structure of the three systems to find the direction in the development of the new Tensegrity structure. Therefore, the results come in a conceptual way that combines the advantages of the structure. Tensegrity The Tensegrity structure brings different systems together. The new system is designed and developed in such a way that it can change the shape of the structure. At the same time, it can cover the floor and increase the size of the structure. The development of a method to simplify the assembly and installation of components with steps. At this time, the appearance of the sub-components within this structure should be uniform. It can be called a modular system, and to prove the ease of assembling the body structure, the pattern of connection points within the structure does not need to be fixed.

1. Shape and size can be changed.
2. Able to cover the area.
3. Able to create shapes that other Tensegrity structures cannot.
4. Easy to assemble and install (modular system).

Table 2 Summary of the Properties of the Different Types of Tensegrity Structure

Type	change shape form	cover the area	easy to assemble	other
dome	✗	✓	✗	
linear	✓	✗	✗	
replicate	✓✗	✓✗	✗	
new type	✓	✓	✓	shape form

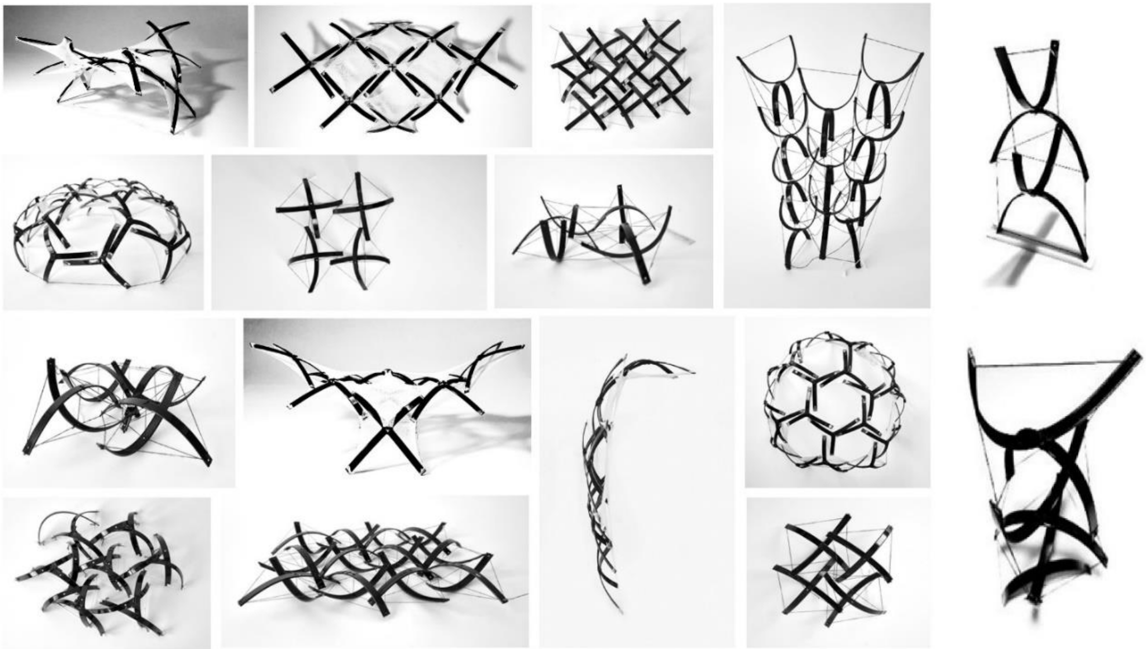


Figure 176 Overview of Tensegrity Structure Experiments

4.1.2 Molecular structure system: Architecture part

Figure 177 S Curve Bridge

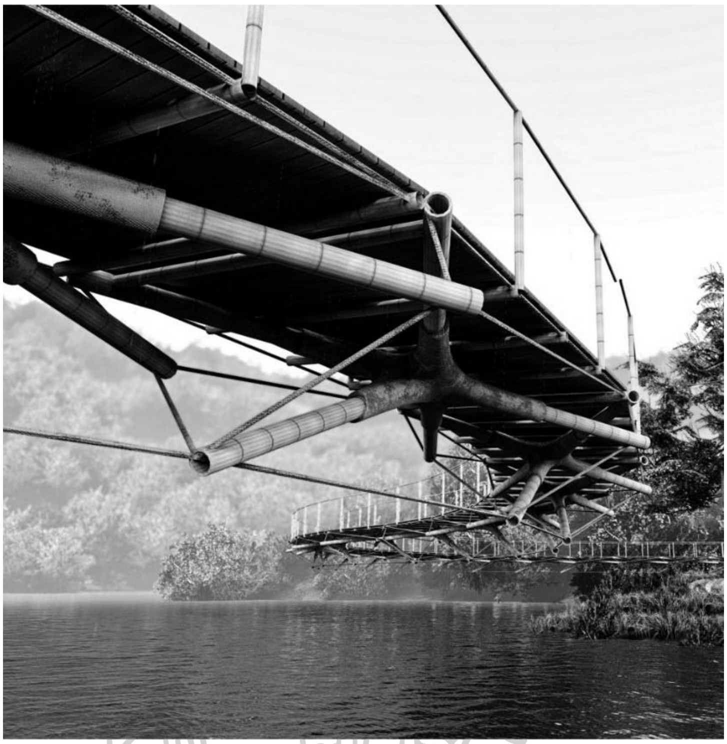


Figure 178 S Curve Bridge

Figure 179 Molecular structure system in Toys part

4.2 Furniture design

4.2.2 Twist Tensegrity Table and Chair set

Figure 180 Tensegrity 3 Legs set

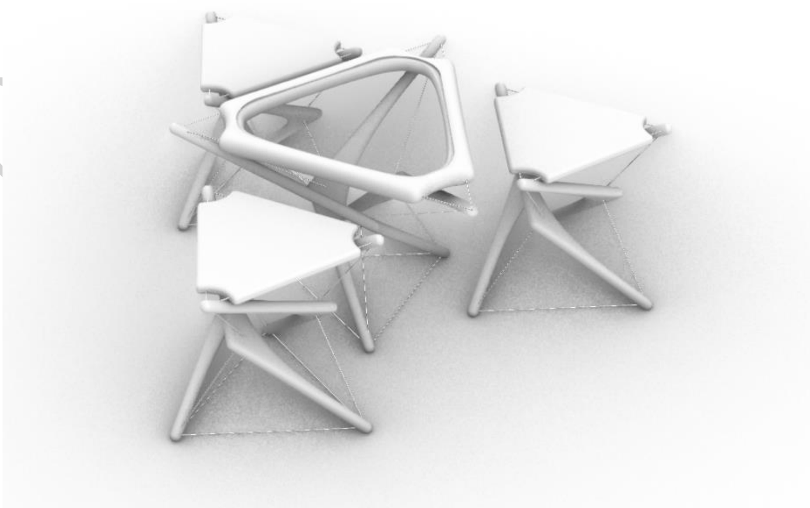


Figure 181 Tensegrity 3 Legs set

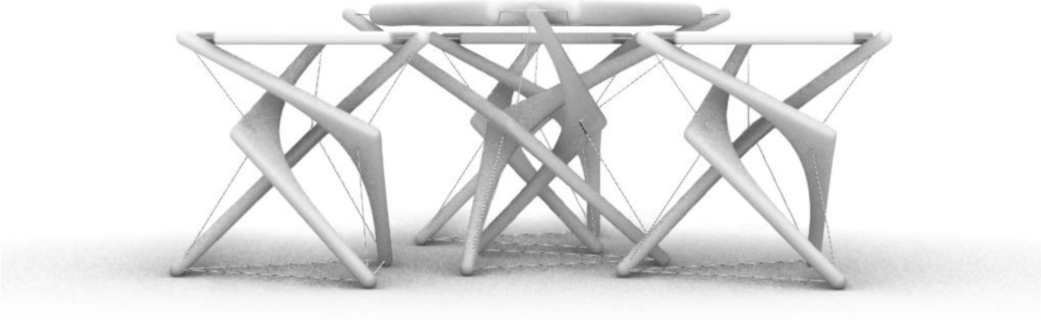


Figure 182 Tensegrity 3 Legs set

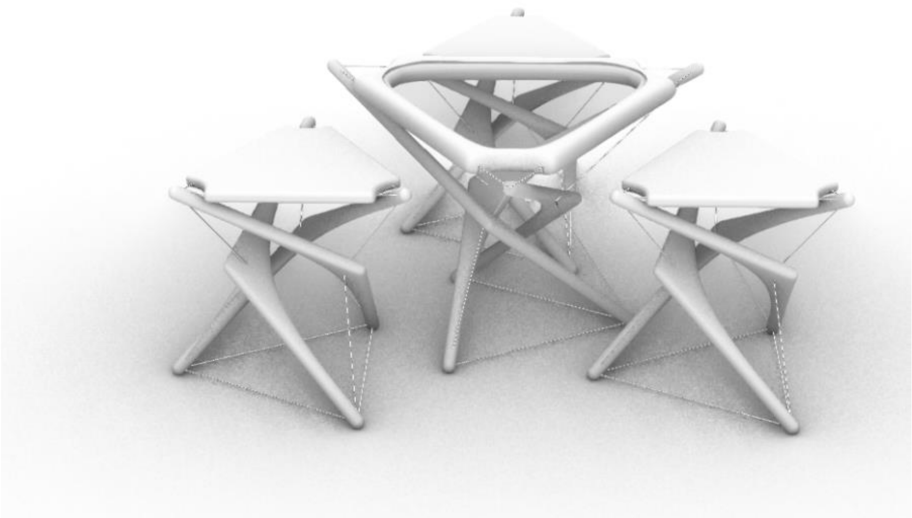


Figure 183 Tensegrity 3 Legs set

Figure 184 Tensegrity 3 Legs set

4.2.3 Twist Tensegrity Table

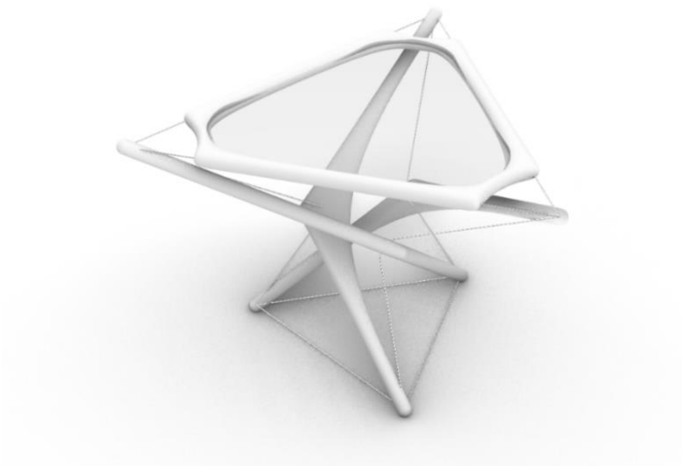


Figure 185 Tensegrity 3 Legs Table

Figure 186 Tensegrity 3 Legs Table

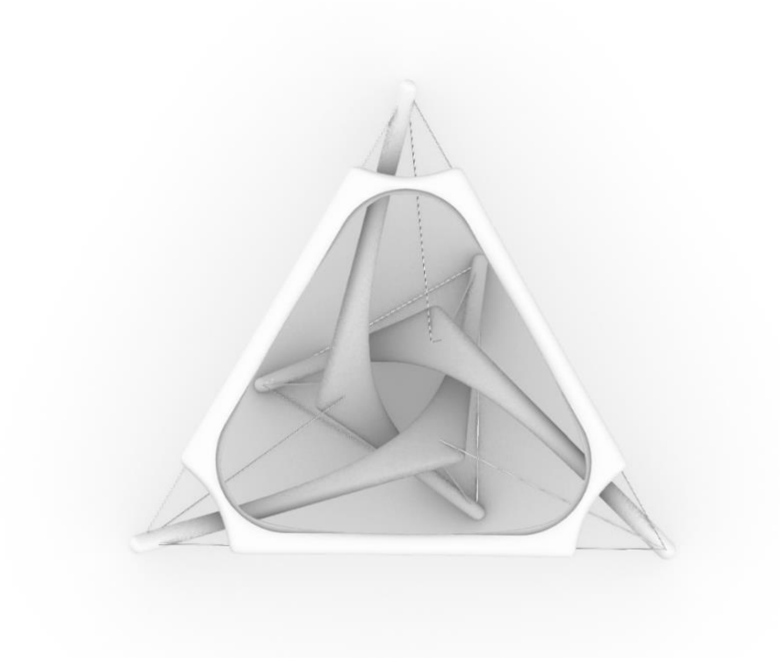


Figure 187 Tensegrity 3 Legs Table

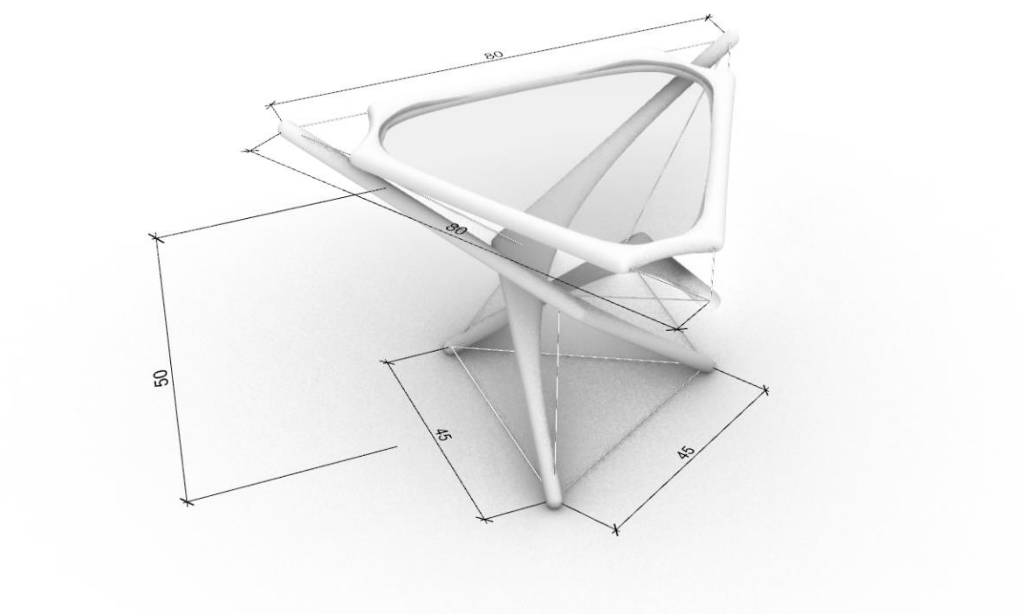


Figure 188 Tensegrity 3 Legs Table

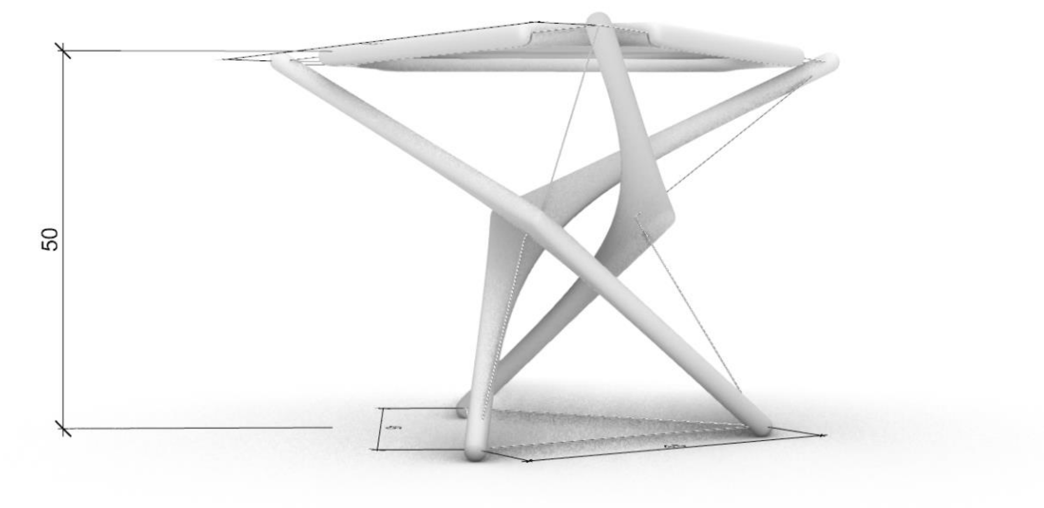


Figure 189 Tensegrity 3 Legs Table

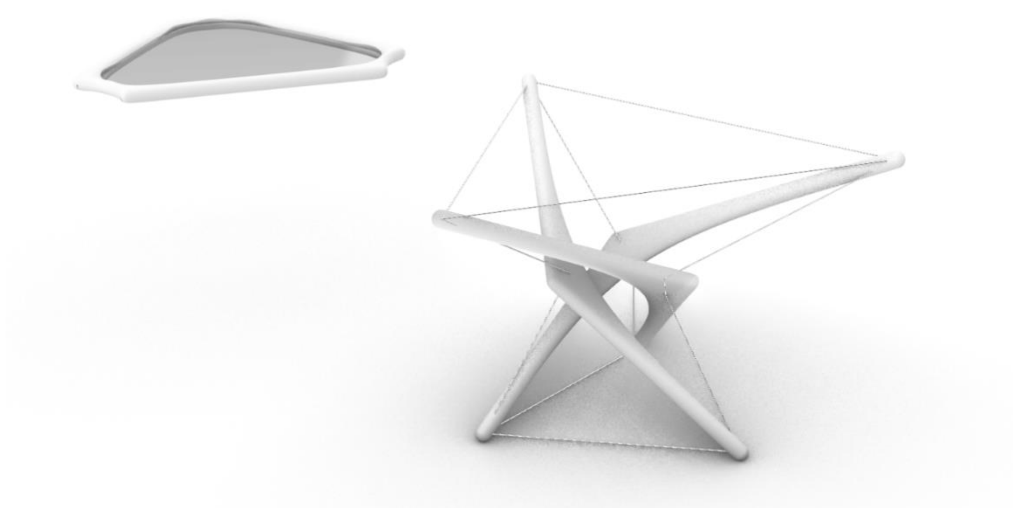


Figure 190 Tensegrity 3 Legs Table

4.2.4 Twist Tensegrity Chair

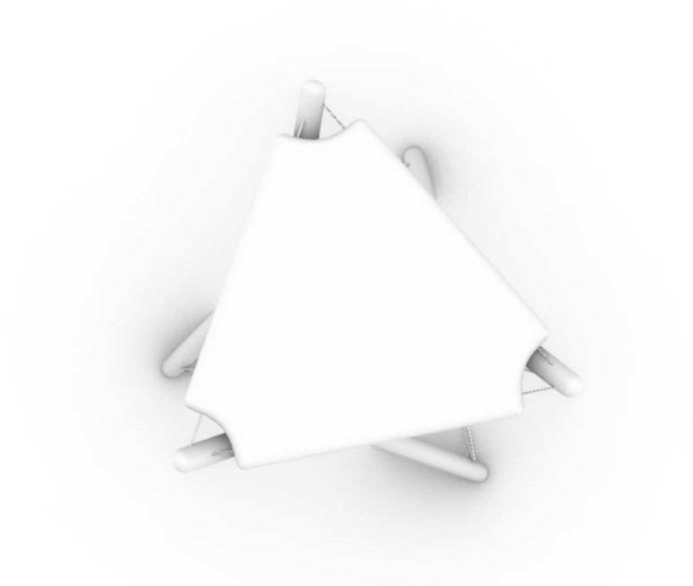


Figure 191 Tensegrity 3 Legged Chairs

Figure 192 Tensegrity 3 Legged Chairs

Figure 193 Tensegrity 3 Legged Chairs

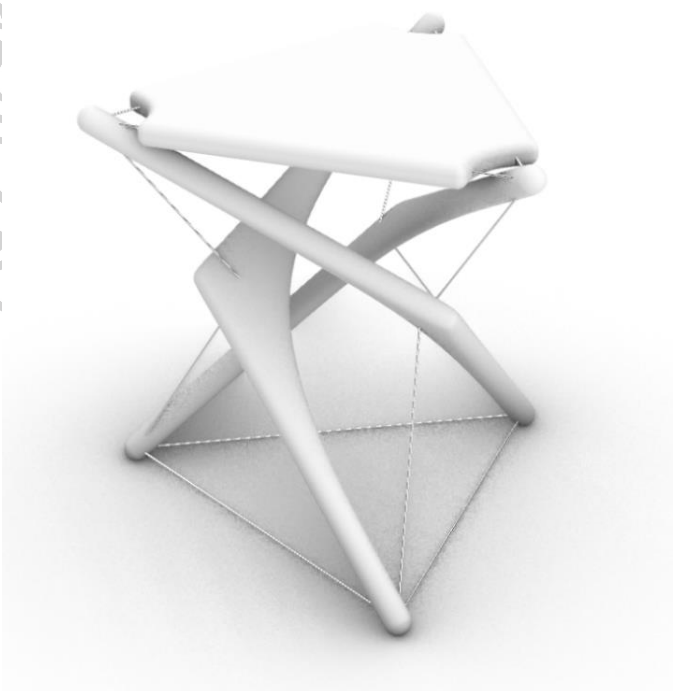


Figure 194 Tensegrity 3 Legged Chairs

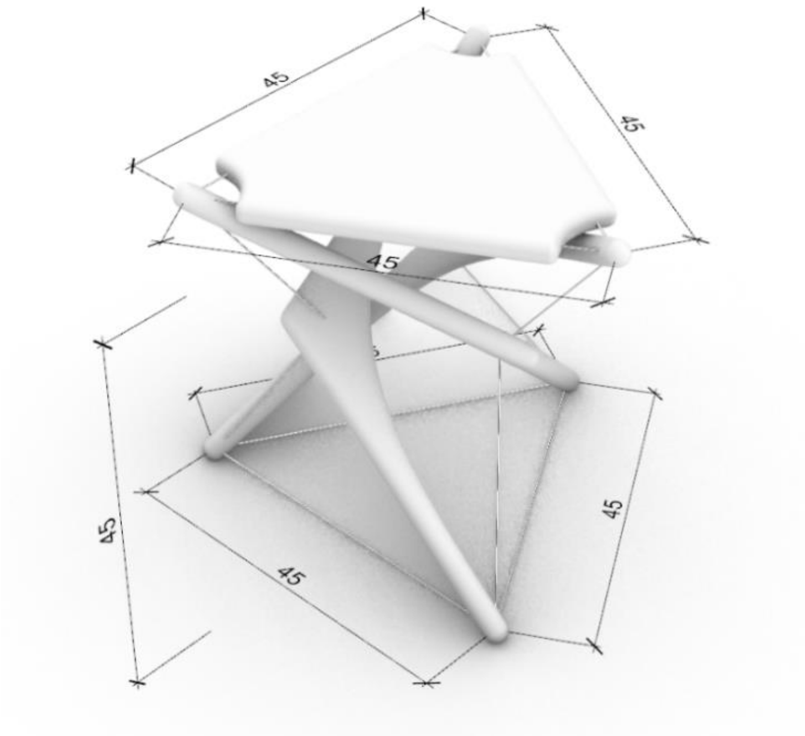


Figure 195 Tensegrity 3 Legged Chairs

Figure 196 Tensegrity 3 Legged Chairs

4.2.5 Balance Tensegrity Side table

Figure 197 Tensegrity Side Table

Figure 198 Tensegrity Side Table

Figure 199 Tensegrity Side Table

Figure 200 Tensegrity Side Table

Figure 201 Tensegrity Side Table

4.2.6 C2-Tensegrity Table and Chair set

Figure 202 C2-Tensegrity Table and Chair set

Figure 203 C2-Tensegrity Table and Chair set

Figure 204 C2-Tensegrity Table and Chair set

Figure 205 C2-Tensegrity Table and Chair set

Figure 206 C2-Tensegrity Table and Chair set

Figure 207 C2-Tensegrity coffee table

Figure 208 C2-Tensegrity coffee table

Figure 209 C2-Tensegrity Table and Chair set

Figure 210 C2-Tensegrity coffee table

Figure 211 C2-Tensegrity table

Figure 212 C2-Tensegrity table

Figure 213 C2-Tensegrity shelf

Figure 214 C2-Tensegrity Table and Chair set

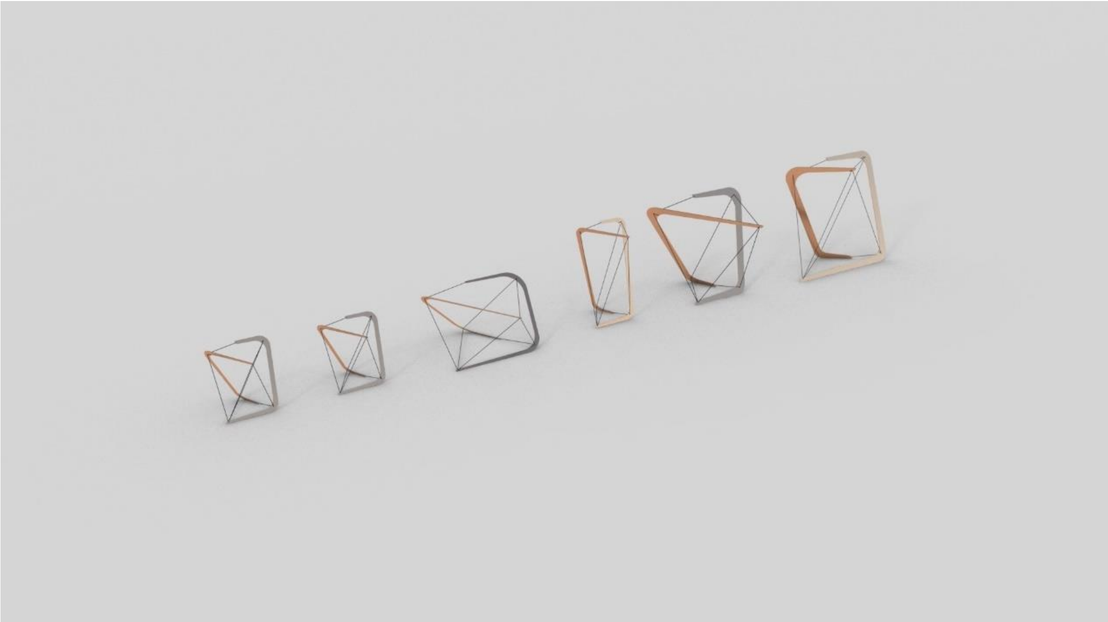


Figure 215 C2-Tensegrity Table and Chair set

Figure 216 C2-Tensegrity Table and Chair set

Figure 217 C2-Tensegrity Table and Chair set

Figure 218 C2-Tensegrity Table and Chair set

Figure 219 C2-Tensegrity Table and Chair set

Figure 220 C2-Tensegrity Table and Chair set

Figure 221 C2-Tensegrity Table and Chair set

Figure 222 C2-Tensegrity Table and Chair set

Figure 223 C2-Tensegrity Table and Chair set

Figure 224 C2-Tensegrity Table and Chair set

Figure 225 C2-Tensegrity Table and Chair set

Figure 226 C2-Tensegrity Table and Chair set

Figure 227 C2-Tensegrity Table and Chair set

Figure 228 C2-Tensegrity Table and Chair set

Figure 229 C2-Tensegrity Table and Chair set

4.2.7 C2-Tensegrity Coffee Table

Figure 230 C2-Tensegrity Coffee Table

Figure 231 C2-Tensegrity Coffee Table

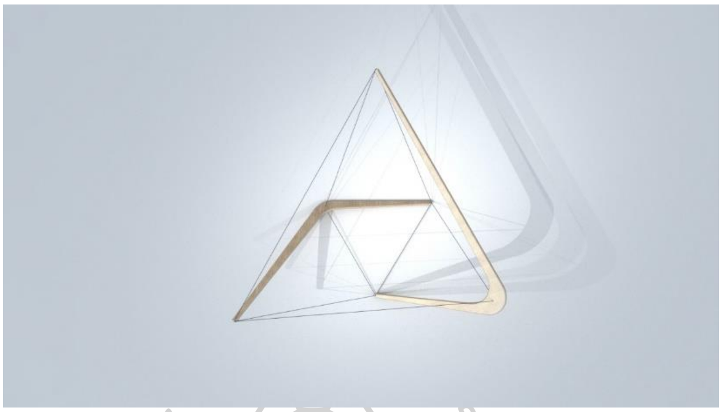


Figure 232 C2-Tensegrity Coffee Table

4.3 Decorative

4.3.1 Twist Tensegrity lamp

Figure 233Twist Tensegrity lamp

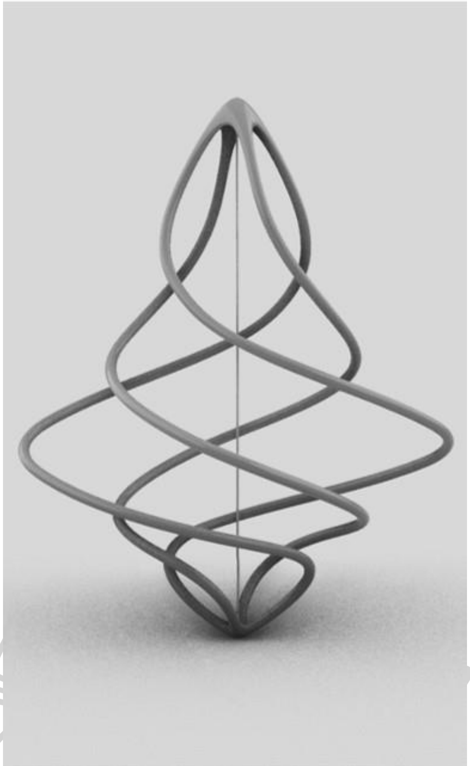


Figure 234 Twist Tensegrity lamp

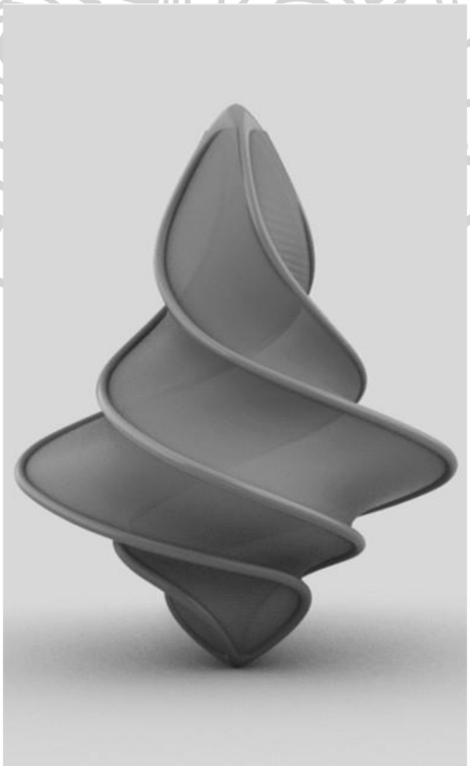


Figure 235 Twist Tensegrity lamp

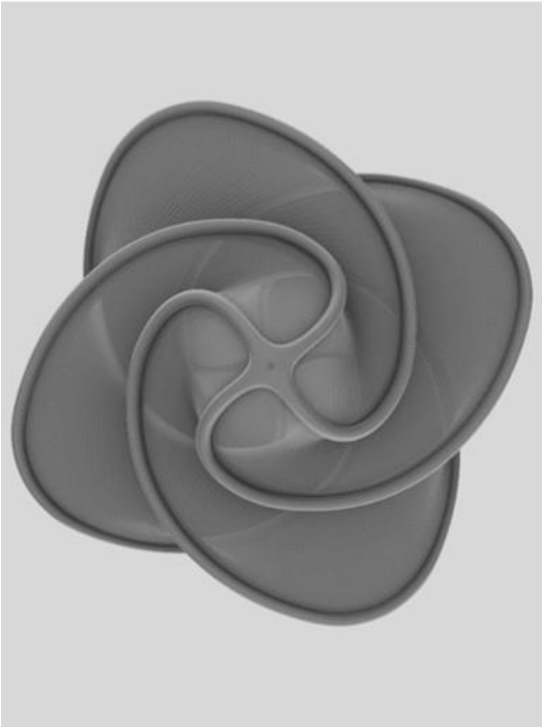


Figure 236 Twist Tensegrity lamp

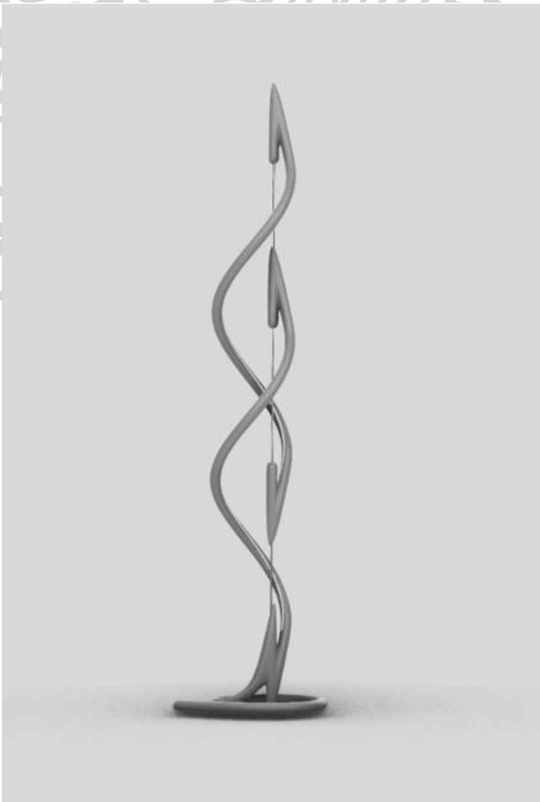


Figure 237 Tensegrity Sculpture

4.3.2 Translucent Tensegrity lamp

Figure 238 Pure Tensegrity lamp

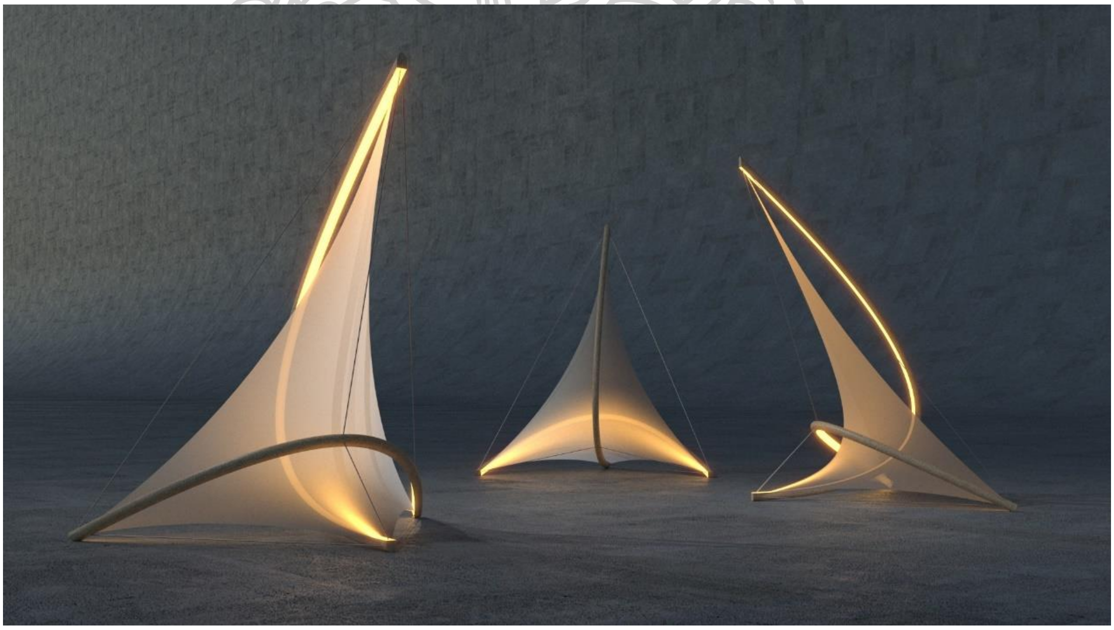


Figure 239 Tensegrity lamp

Figure 240 Tensegrity lamp

4.3.3 Pure Tensegrity lamp

Figure 241 Pure Tensegrity lamp

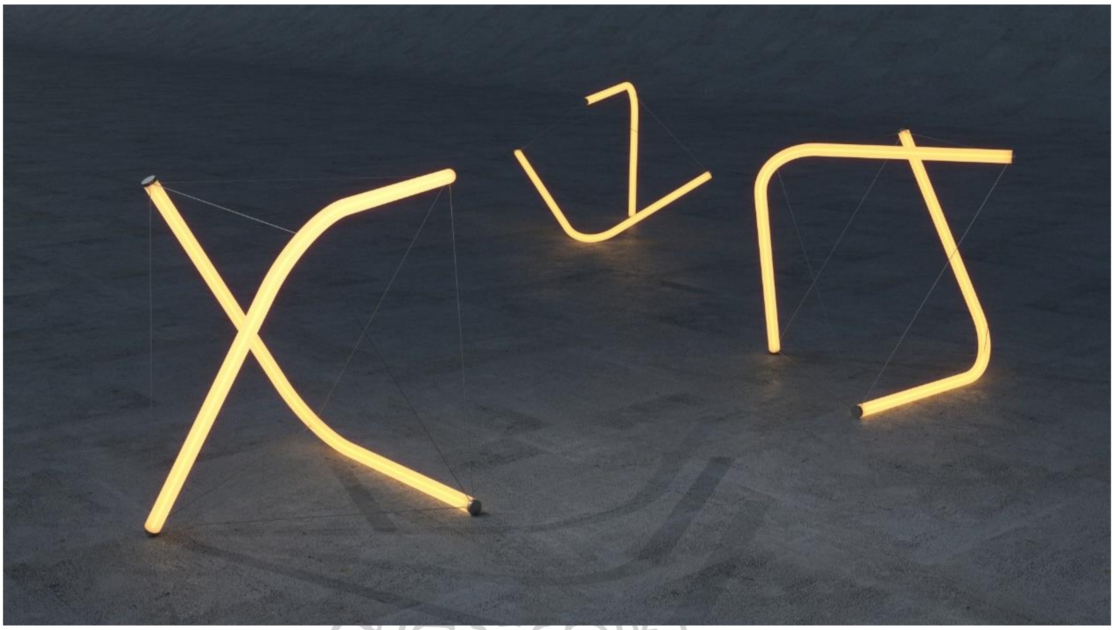


Figure 242 Pure Tensegrity lamp

Figure 243 Pure Tensegrity lamp

4.3.4 Tensegrity lamp with decorate celling in interior design

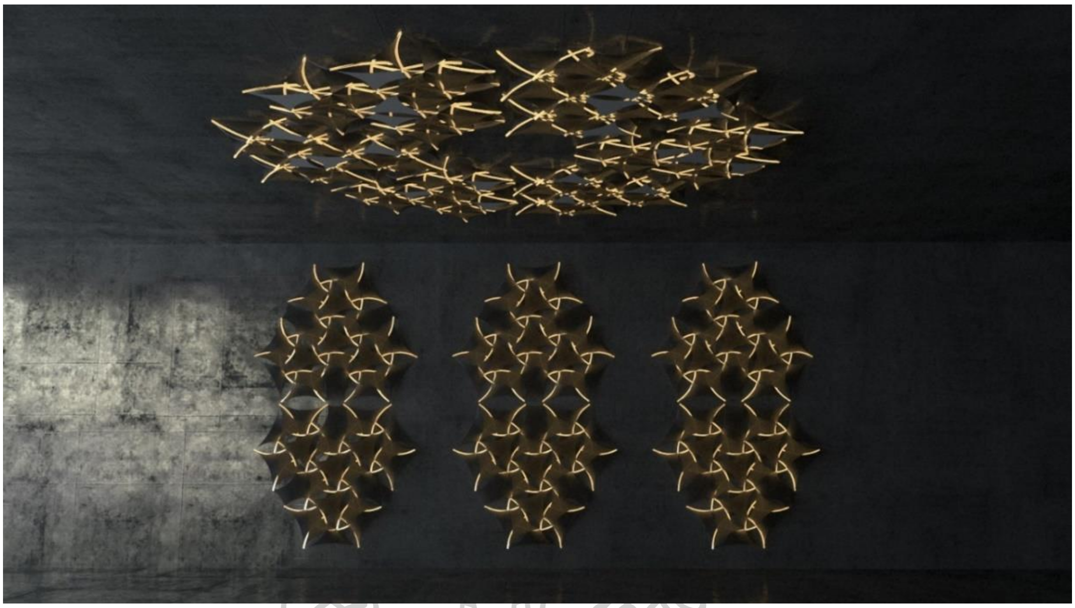


Figure 244 Tensegrity surface lamp

4.3.5 Tensegrity Sculpture

Figure 245 Tensegrity Sculpture

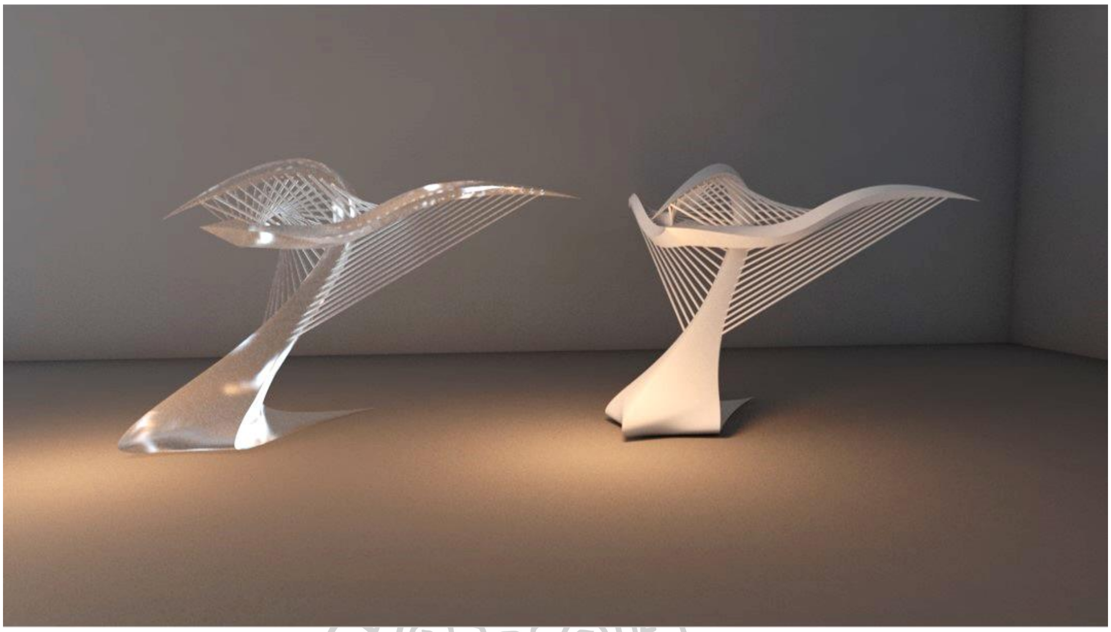


Figure 246 Tensegrity Sculpture

4.3.6 Molecular structure system: Sculpture

Figure 247 Molecular Structure for Sculpture

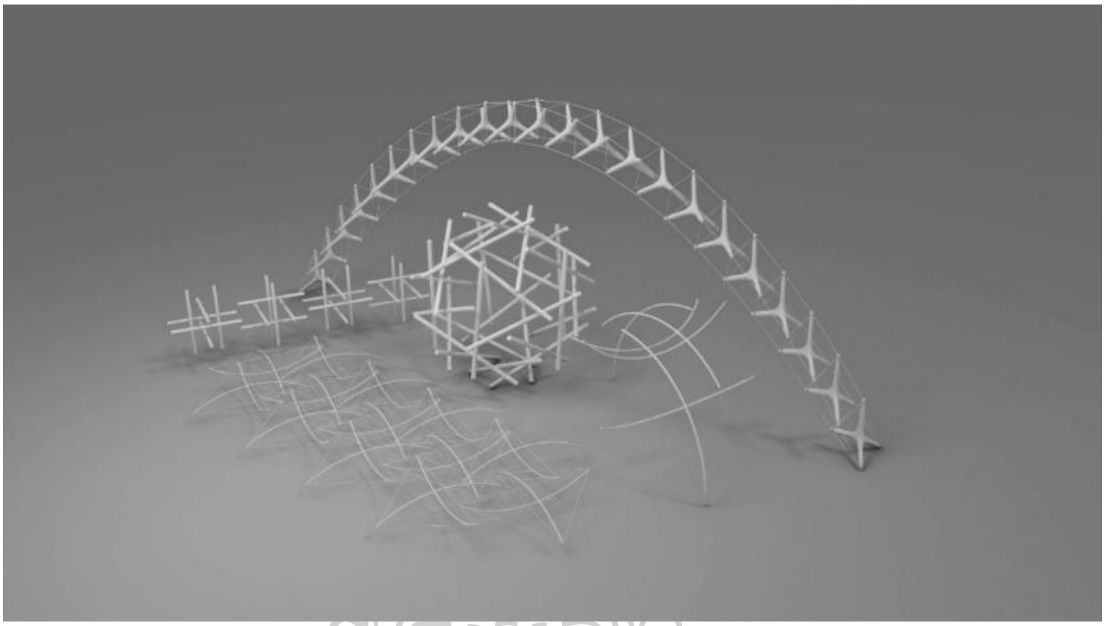


Figure 248 Models for simulating other forms of Tensegrity structures

4.3.7 Molecular structure system: Toys part

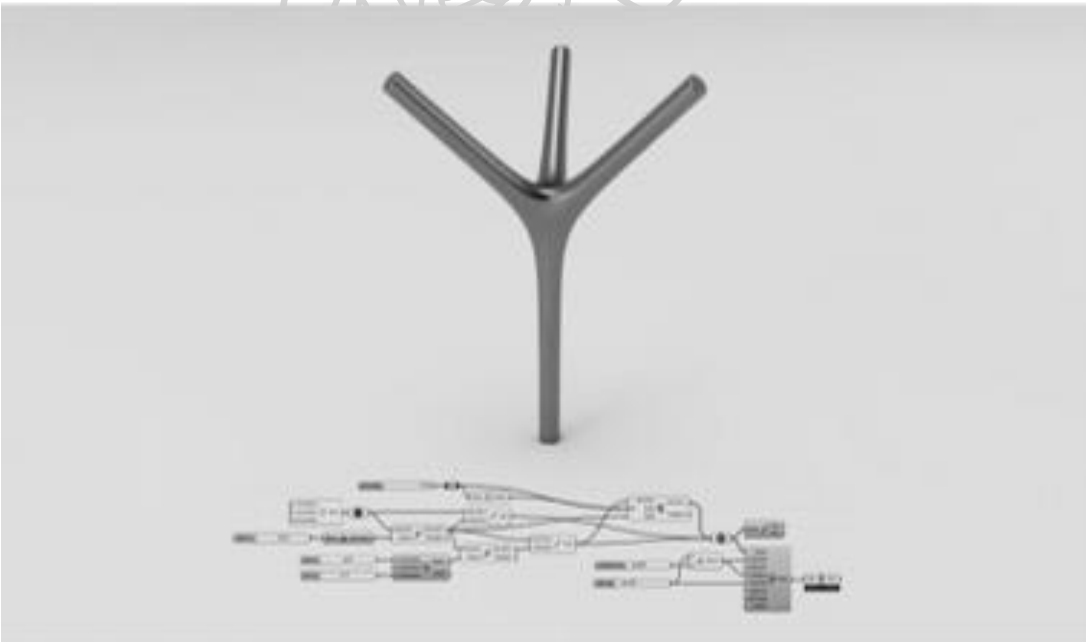


Figure 249 Molecular structure system in Toys part

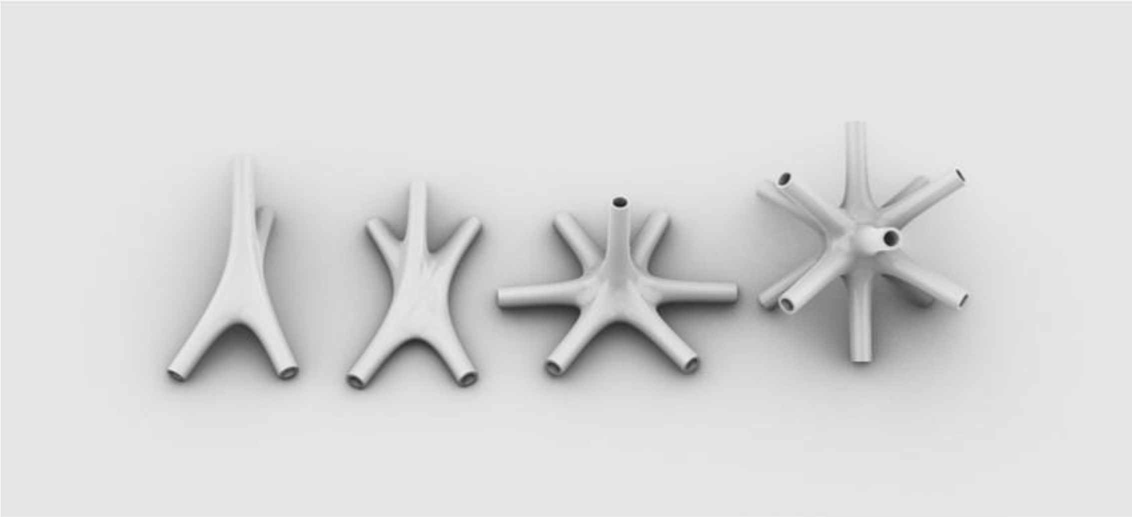


Figure 250 The joint part of the molecular structure system

Figure 251 Molecular structure system in Toys part

Figure 252 Molecular structure system in Toys part

4.4 Application

The theory and principles of Tensegrity Structures can be adapted into many different forms. To effectively utilize these principles, one must begin by studying the properties of the structures to tailor their application to various design tasks. The theory and principles of Tensegrity Structures apply to a broad range of concepts in architecture and engineering. However, the production and installation steps, which require specialized tools to generate substantial tensile forces, must be considered, particularly in mechanical work. Furthermore, the concepts and principles associated with Tensegrity structures can be applied to designs that require both functional utility and aesthetic uniqueness, such as furniture that needs to be both strong and distinctively appealing.

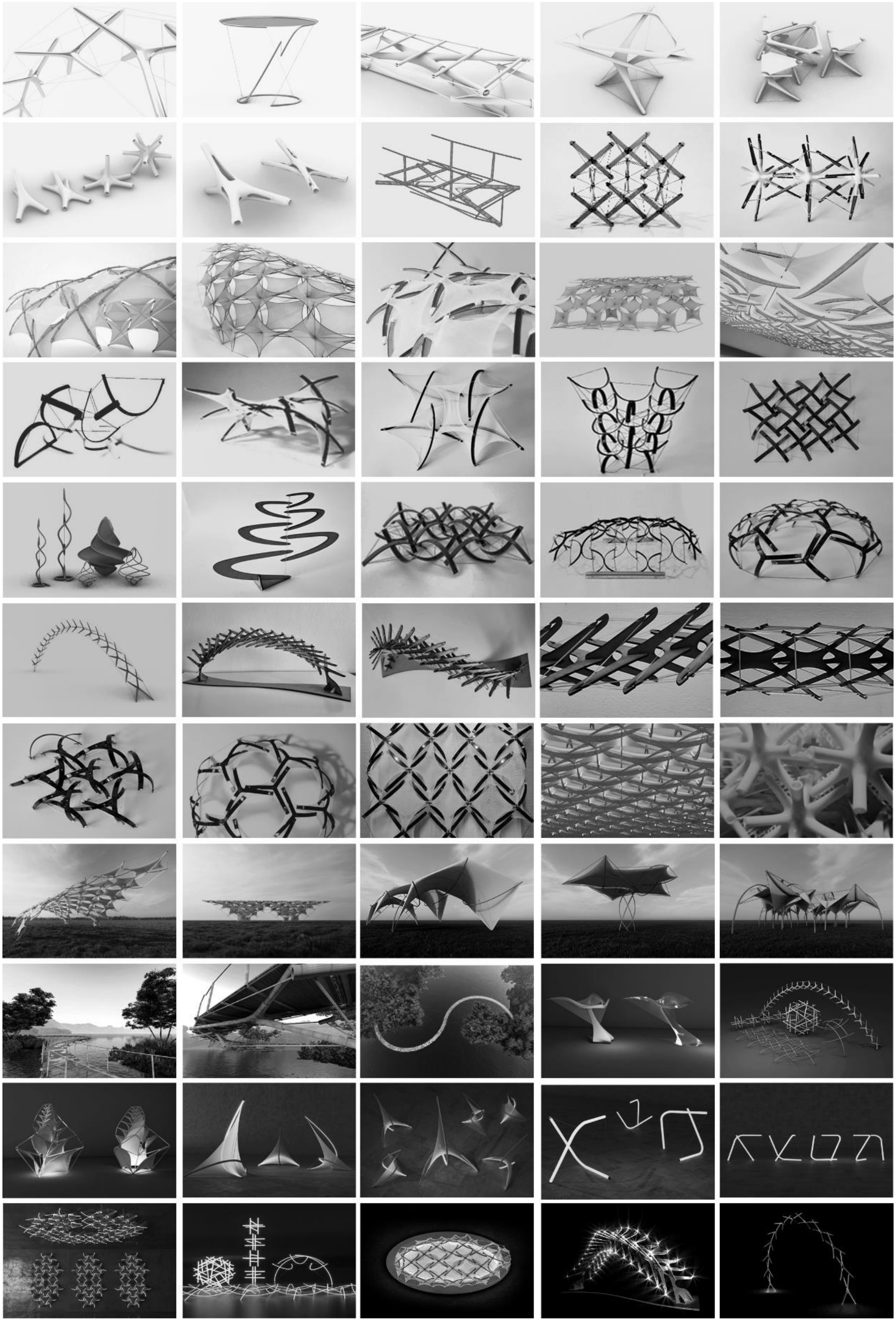


Figure 253 Applications of Tensegrity structures

Chapter 5

Conclusion

5.1 Conclusion

Tensegrity structure is often applied in a wide range of works, specifically in structural composite (René Motro 2012) due to the lightweight and flexibility. However, the system that connects the individual parts within the structural elements is complex and the assembly process is laborious. The advantages are straightforward as indicated by the significant reduction in the mass receiving loads (Ma, Chen, and Skelton 2022). However, the application for architectural structures is limited due to the different shapes and sizes that need to be fulfilled. Each component within the structure is essential and relevant to other elements. This means that each part must be integrated step by step, especially when connecting the parts. Therefore, this research was conducted to achieve three objectives.

The first objective was to study and investigate the historical evolution and development of Tensegrity structures, focusing on individuals closely Tensegrity in architecture, and to find principles and definitions of the structure. The results brought more clarity on the two individuals Buckminster Fuller and Kenneth Snelson. These individuals were instrumental in developing the concept and demonstrating its operating principles and potential. This is because the principles were defined as a structure consisting of parts that absorb compressive and tensile forces to form or maintain a solid shape without the compressed parts sticking or touching each other.

The second objective was to categorize the structures based on their properties in order to facilitate the appropriate application in design and to create, develop and design new types of Tensegrity structures. Tensegrity structure also categorized based on their properties and the ability to change shape direction and virtual space coverage as a skin. This led to the discovery of three types, including 1. the tensegrity dome structure, 2. the tensegrity structure, and 3. the self-repeating tensegrity structure. The properties of these types were combined to design a new tensegrity structure that allows expansion in width and length. Existing knowledge of tensegrity structure was used to develop a new model that meets the architectural requirements of shape and form by combining some properties of the previous types. Tensegrity was structurally designed as a pavilion with a curved roof shape that could not be achieved by any of the three existing systems. The size of the shape could be customized to a certain extent. Moreover, the experimental results showed that the mixed system was designed with a unit orientation that was associated with an increase in the number of dome systems of the tensegrity structure. It was also found that the model had tensile connections like the linear tensegrity structure. The existence of these two features should allow the new model to increase or decrease the number of units required and thus control the shape of the structure. This research served to demonstrate the methods for the development of a new type of tensegrity structure, the so-called mixed tensegrity structure with double layers. The general structure should have the ability to cover an area, be surface-based and create shapes that were considered impossible for previous tensegrity structure types. It should also be easy to assemble and install so that it can be used in different constructions. The structure also needed to have a large span, withstand significant forces and weights despite its light weight, and stabilize internal force distribution.

The third objective was to Tensegrity structures in art and design by promoting a deeper understanding of the interplay between Tensegrity principles and application concepts in functional and esthetic design in furniture design. This research has revealed the necessary insights for the development of a novel Tensegrity structure characterized by a double-layered support. When this innovation is integrated into the furniture design process, it leads to a remarkable reduction in compressive forces. The result is furniture with minimal compressive forces while maintaining structural strength.

5.2 Discussion

The main objective was to describe the principles and definitions of structures, focusing on the working principle of Tensegrity. Tensegrity is characterized by a configuration that includes two basic forces, namely compressive and tensile forces. In this system, the components subjected to compressive forces either remain unconnected or connect without direct contact.

The secondary objective was to classify structures based on their properties and thus facilitate their appropriate application in design. This objective also included the creation, development and design of novel Tensegrity structures. The innovative Tensegrity a second level of tension, which can be achieved by adding a cable mesh or by adjusting the deformation of compression elements.

The third objective focused on Tensegrity structures into the fields of art and design and fostered a deep understanding of the interplay between Tensegrity principles and application concepts. This understanding extends to considerations of functionality and esthetics in the context of furniture design.

As a result of the design process, this furniture collection is based on the concept of using the structural foundation derived from the new Tensegrity structure. The principles of the Tensegrity with the idea of an aerobic body, resulting in a structure characterized primarily by compressive components. The two resulting pieces Tensegrity furniture with the fewest compressive elements to date, offering potential benefits in terms of reduced complexity in assembly and installation.

5.3 Suggestions

Although the assembly challenges have been successfully overcome, the newly developed structure is still considered complicated compared to alternative structural forms. With this particular type of structure, especially in scenarios that require significant force or weight support, it is imperative to consider the use of tools or equipment that can facilitate the installation process.

The operating principle of the tensegrity structure is based on the interaction of compressive and tensile forces. This means that the strength depends on the material chosen for both the compression and tension parts. At the same time, the strength of the material also increased the potential obstacles that could be encountered during installation, which indicated the need to focus on the type of tools to be used. Tensegrity structure had continuous tensile forces, which showed that damaging one part, be it a compression or tension part, could result in the entire piece needing to be kept in balance. It was also necessary for the experimenter to control and install the workpiece in a strong, stable and careful manner.

5.4 Contribution

Tensegrity was classified on the basis of its properties and ability to change shape direction and area covered. The criteria were derived primarily from the need to develop a new type of structure applicable in extensive architectural design, focusing on spatial divisions requiring a variety of shapes and sizes. This knowledge and method suited architects, engineers and designers who were interested in a wide-span structure that was light, could change shape and was highly stable. Tensegrity structures offer unique advantages such as light flexibility and stability. In the field of architecture, these structures are used to promote innovative designs and the construction of earthquake-resistant buildings. In the field of robotics, tensegrity structures enable the development of adaptable and resilient robots. Tensegrity structures are attracting interest in various fields of engineering, architecture and design as they encompass both functional and esthetic considerations.

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