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PRINCIPLE OF TENSEGRITY

Submitted in partial fulfillment of the requirements of the degree of

Masters of Design

by

Tarun Pahadiya

22M2234

Project guide

Prof. Avinash Shende

IDC School of Design

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

(2024)

Approval form

This document serves as official confirmation that the Industrial Design Project titled "PRINCIPLE OF TENSEGRITY" authored by Infant *Tarun Pahadiya* has been sanctioned for partial fulfillment in pursuit of the Master of Design degree in Industrial Design.

Prof. Avinash Shende
[project guide]

Signature of the
chair person.

Signature of the
Internal Examiner

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External Examiner

Declaration form

I declare that this written submission represents my ideas in my own words and, where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented, fabricated, or falsified any idea, data, fact, or source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Tarun

Signature:
Name of he student: Tarun Pahadiya
Roll number: 22m2234

Abstract

"The core intention of this project centered on an in-depth exploration of tensegrity principles, with the ultimate goal of translating this knowledge into the creation of an industrial product. The specific objective revolved around the effective application of tensegrity principles in a manner where traditional structures fall short, highlighting the unique strengths of tensegrity in practical design.
The intended impact of this project is threefold: to usher in innovation within design paradigms by leveraging the inherent strengths of tensegrity, to offer a product that not only showcases aesthetic appeal but also functional utility through its motion and structural novelty, and to broaden the application of tensegrity principles in a tangible, accessible manner. The vision encompasses achieving the perfect equilibrium between aesthetics, motion capabilities, and novelty, thereby establishing a new benchmark in design innovation through the application of tensegrity principles."

Acknowledgement

I wish to convey my sincere appreciation to my mentor, Professor Avinash Shende, for his indispensable guidance throughout the project. I extend my special thanks to the professors of the Industrial Design Department for their constructive critiques and valuable guidance. My gratitude also extends to all the instructors, staff, and students at the Industrial Design Centre (IDC) for their unwavering assistance, insightful advice, and helpful suggestions. I am particularly thankful to our lab assistants for their technical guidance. Lastly, I would like to express my deep appreciation to my family and friends for their steadfast support.

Index

Overview of the project

"The project aimed to delve into tensegrity principles, culminating in the creation of an innovative desk lamp that embodies the foundational concept of 'mast' within tensegrity structures. This lamp stands out through its creation of a visual illusion, seemingly floating due to the arrangement of solid elements. Additionally, it boasts unique motion capabilities owing to its tensegrity-based design.

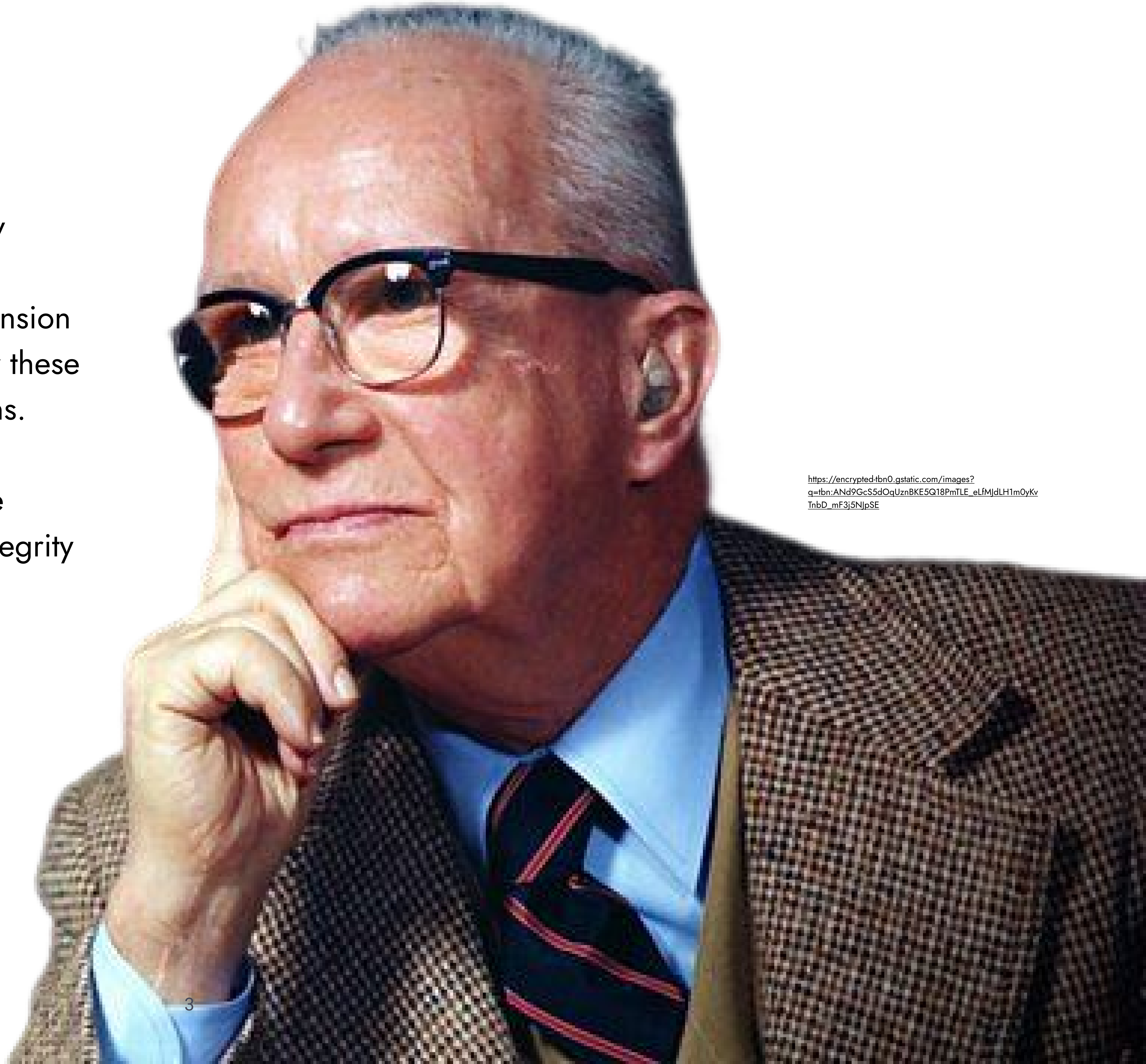
The significance of exploring tensegrity lies in the untapped potential it offers within the realm of structural design. Notably, the ability to suspend solid objects in space by leveraging tension balance presents a novel avenue, promising both aesthetic and functional value.

The path to designing this lamp was challenging, with complexities in structure, light placement, use cases, and material selection. However, meticulous problem-solving resulted in a flexible and aesthetically appealing desk lamp. Beyond conventional use, this lamp strategically leverages tensegrity structures, showcasing their applicability in ideal environments. This overview encapsulates the project's essence, emphasizing its goals, innovations, challenges, and intended use.

Introduction

Evolution and history

Buckminster Fuller, a pioneering architect, greatly influenced tensegrity structures. Coining the term "tensegrity," he emphasized structures held by tension and compression. His geodesic domes exemplify these principles, showcasing lightweight, strong designs. Fuller's contributions extend beyond architecture, impacting biology and robotics. His work laid the groundwork for understanding and applying tensegrity principles in resilient and adaptive structures.



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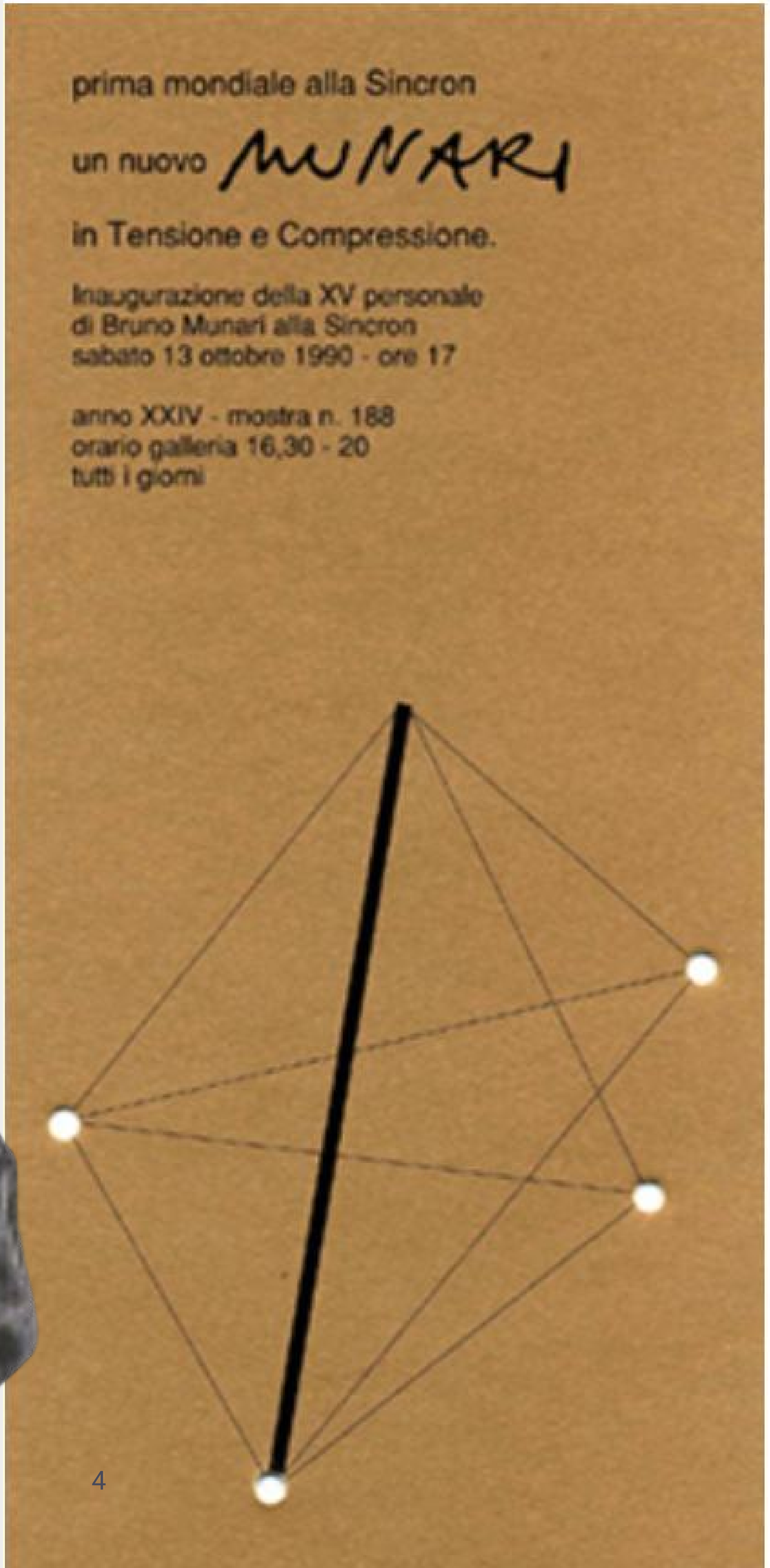
Buckminster Fuller

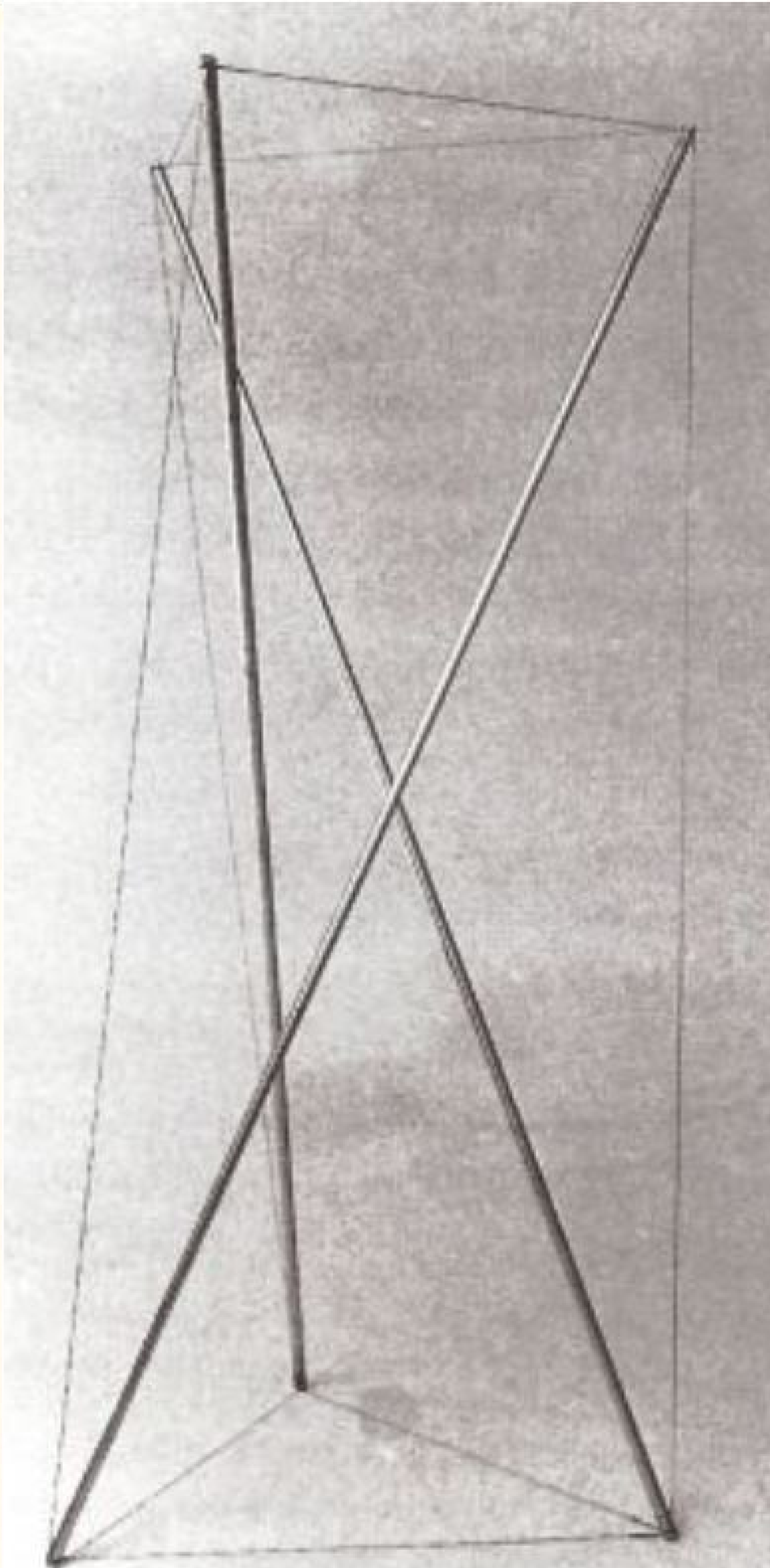
Who first coined the phrase in his 1962 patent application.

Bruno Munari

[photograph published in the catalog of the Alta Tensione exhibition, Milan 1991]

Bruno Munari, the renowned Italian artist and designer of the 20th century, may not have directly explored tensegrity structures. Still, his design philosophy, emphasizing simplicity and material understanding, resonates with the principles underlying tensegrity.





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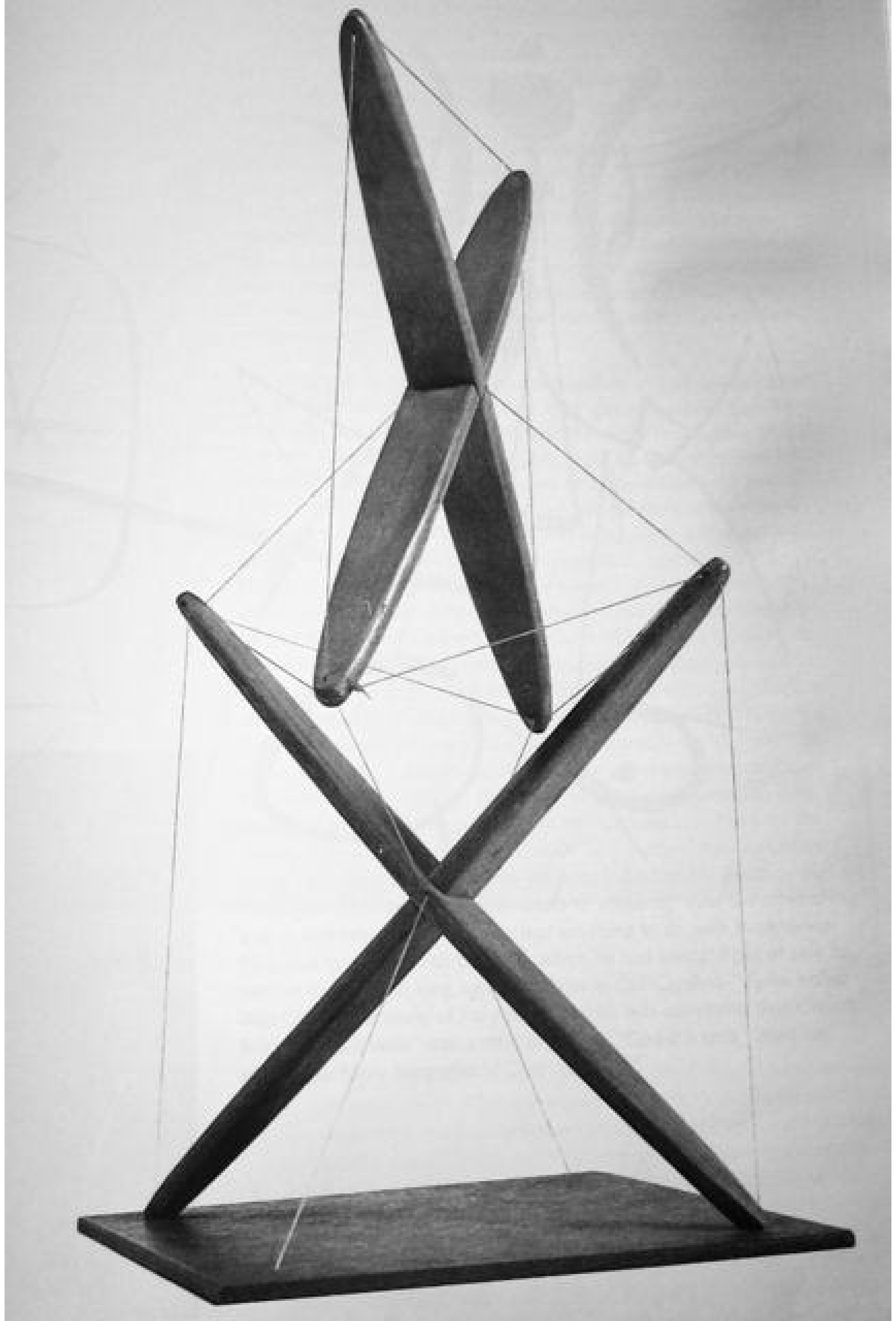


X- piece sculpture in 1948.

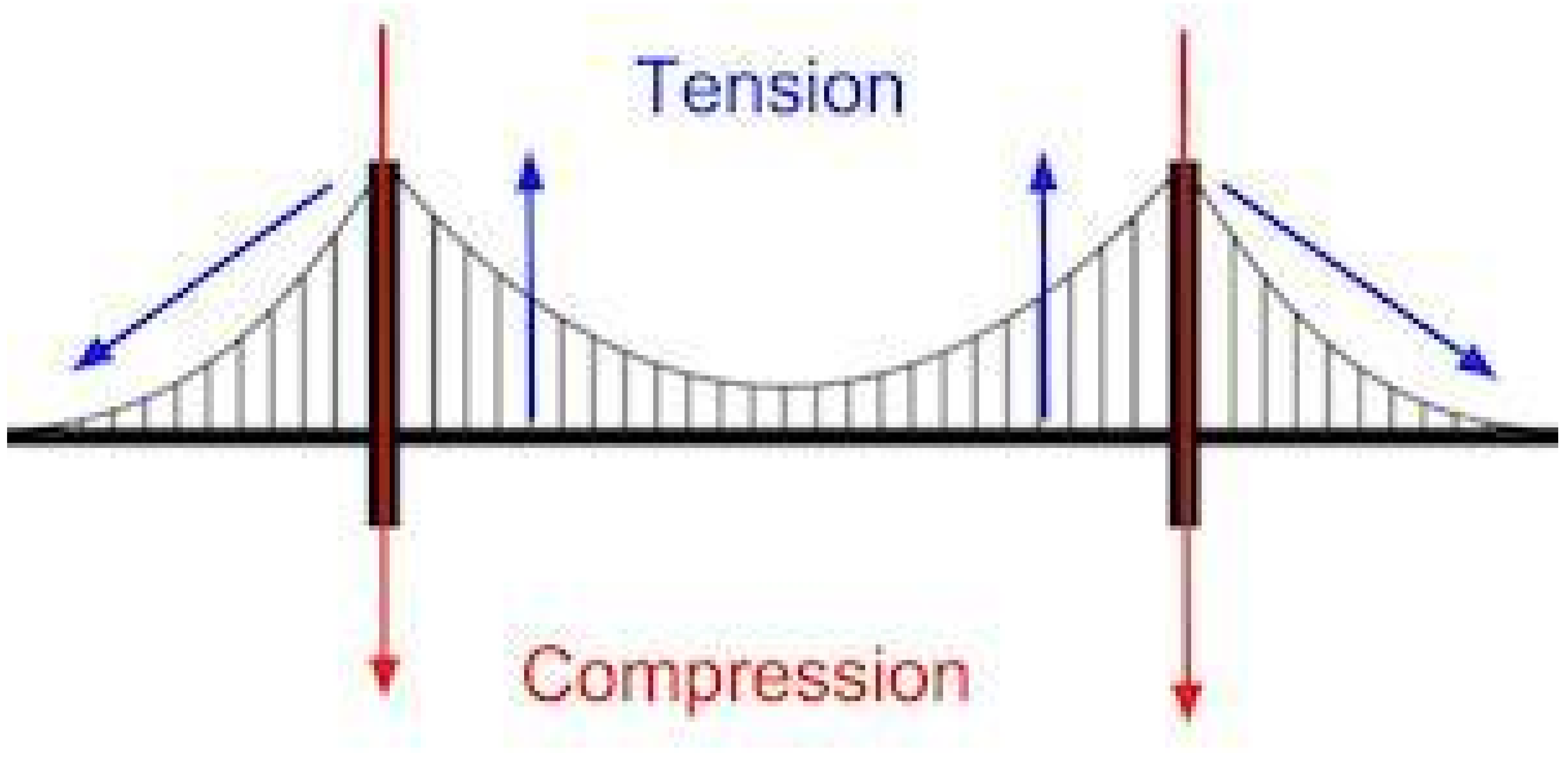
The first true Tensegrity structure is however attributed to the artist ***Kenneth Snelson***.

The "X-Piece" sculpture, created in 1948, stands as a testament to the artistic ingenuity of its creator. This notable artwork showcases a harmonious blend of form and expression, encapsulating the creative spirit of its time. The sculpture's innovative design and aesthetic significance contribute to its enduring legacy in the realm of modern art.

SOUTH BANK EXHIBITION, FESTIVAL OF BRITAIN 1951
FROM THE RIVER

Explanation of tensegrity principle

Tensegrity principles involve a structural system where components, like rods and cables, are held in a state of continuous tension and isolated compression. The balance between tension and compression elements enables stability despite the appearance of complexity. These principles have sparked interest across multiple fields due to their ability to create lightweight, adaptable, and resilient structures.



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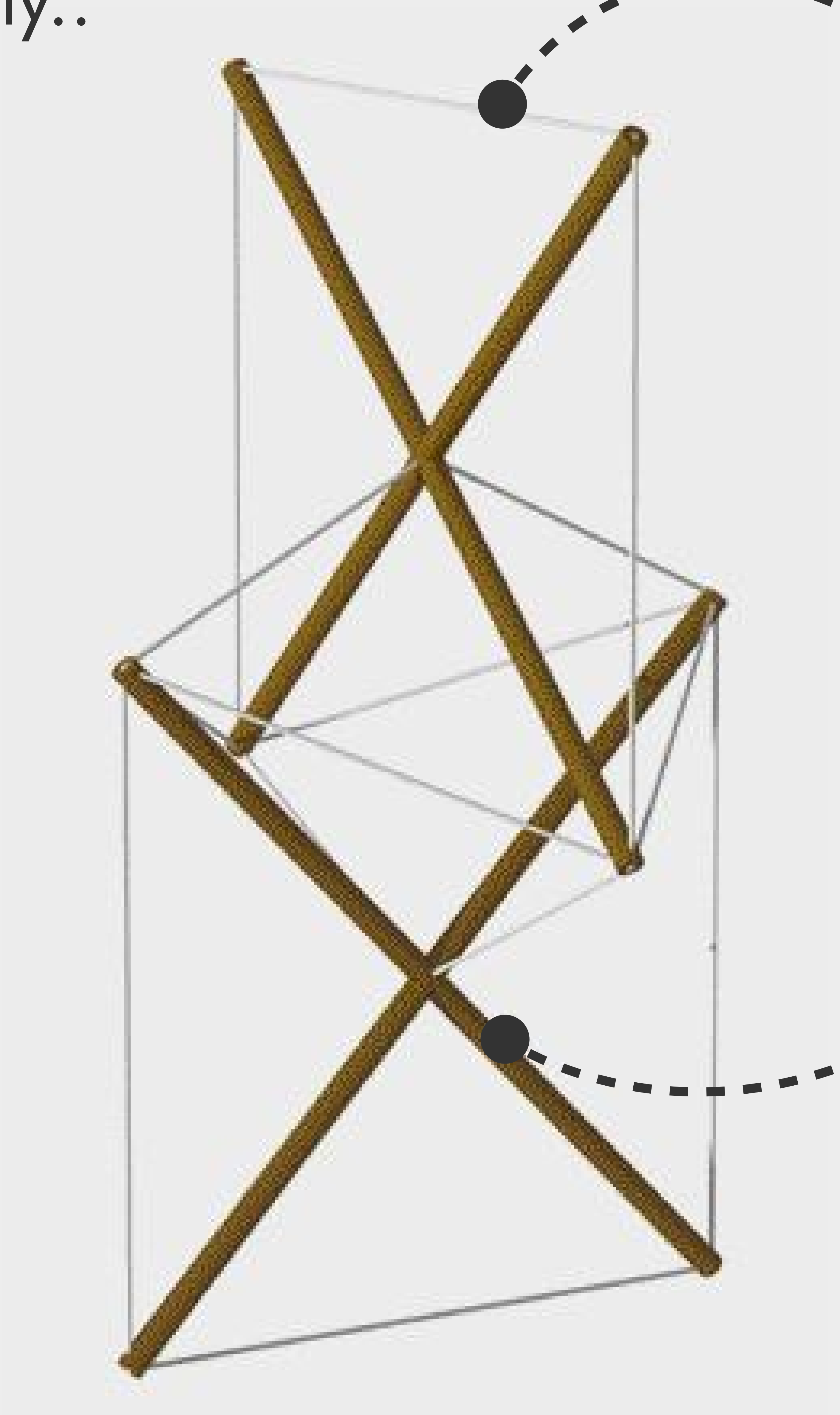
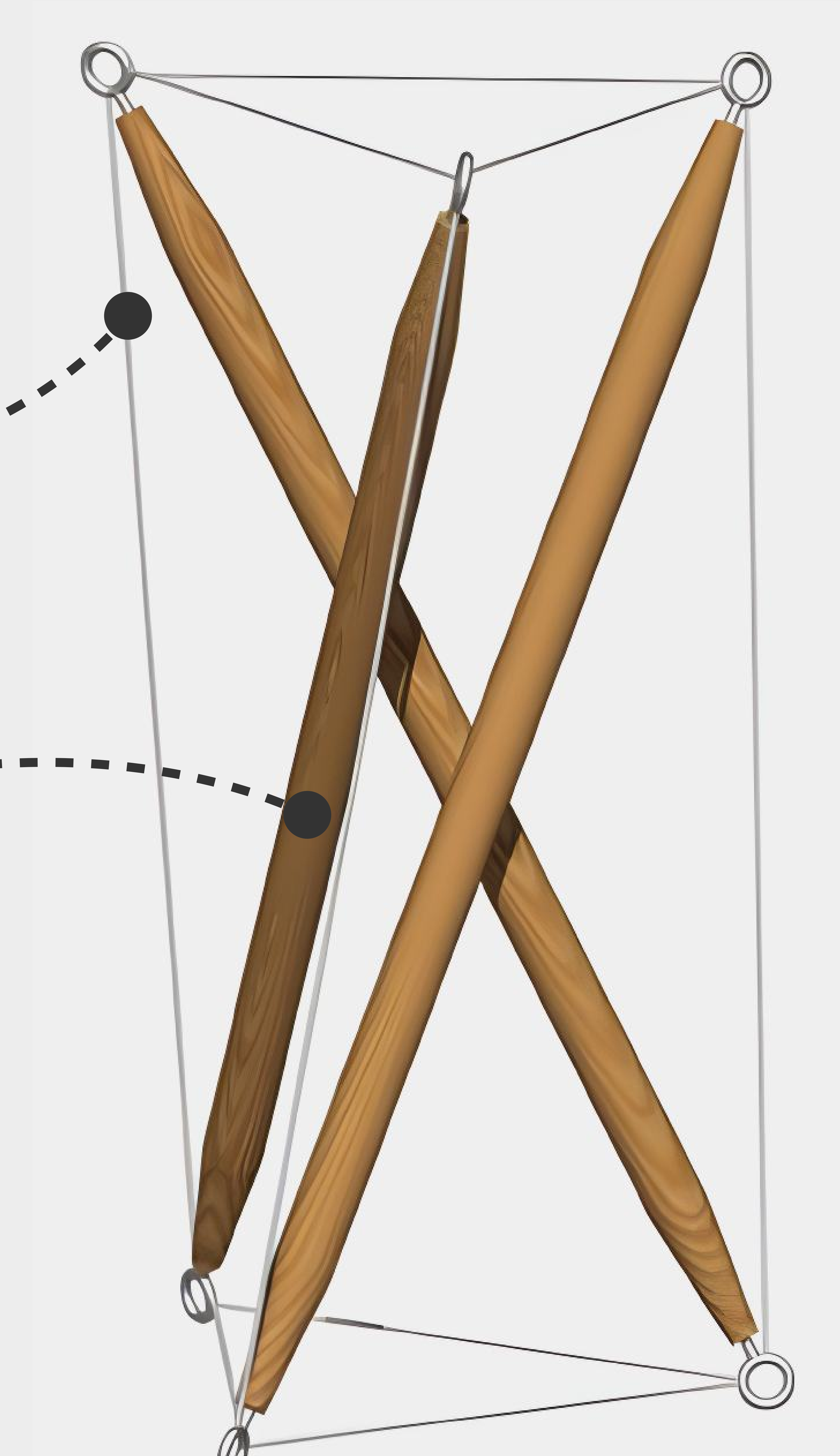


Wire in tension

Solid in compression



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Current use of Tensegrity

Currently, the principle of tensegrity is predominantly employed for aesthetic purposes rather than substantial functionality. It is often utilized as a design element, with a focus on creating illusions, particularly in furniture and architectural installations. However, the unique functional aspects of tensegrity are largely overlooked, possibly due to the perceived complexity associated with its practical application. The potential for leveraging tensegrity principles in functional and innovative ways remains an untapped avenue within current design practices.

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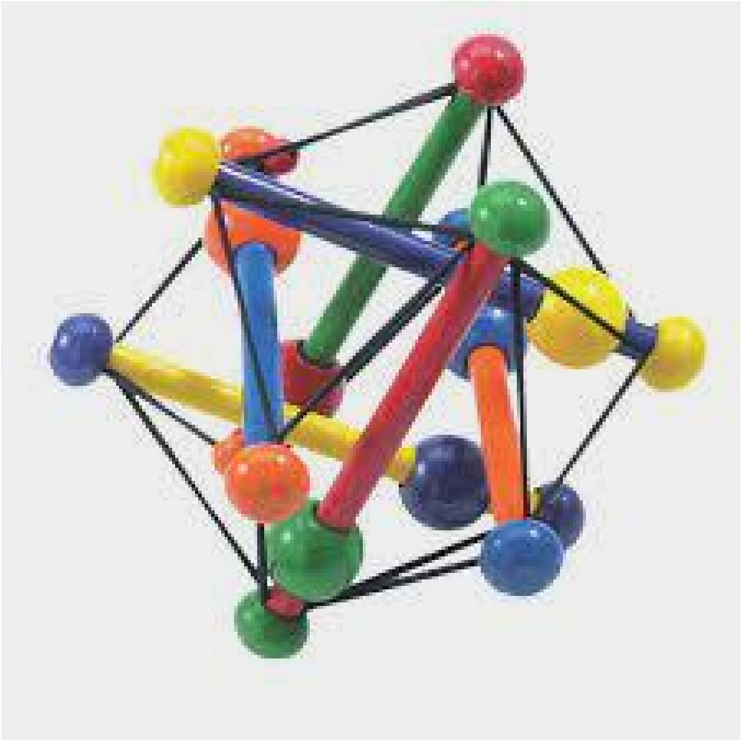

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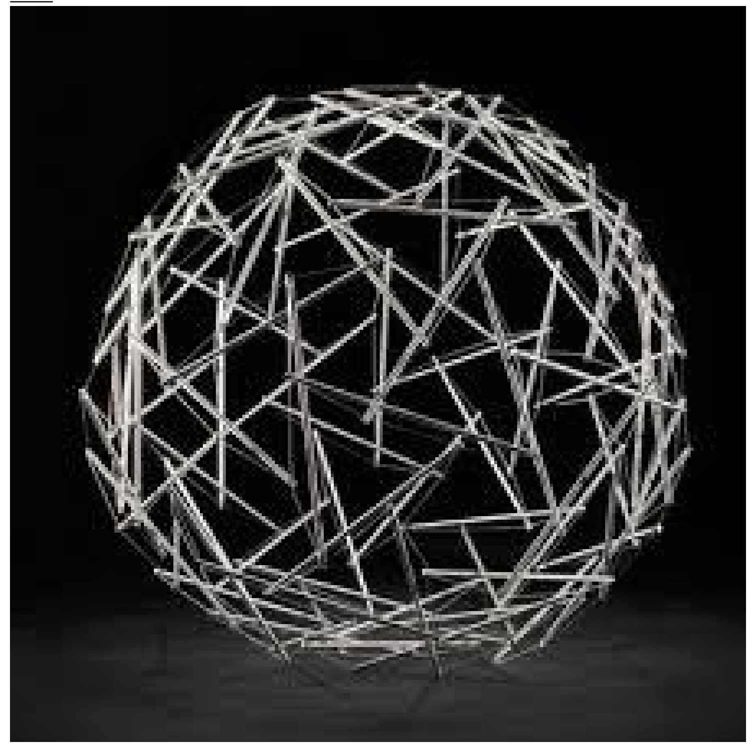

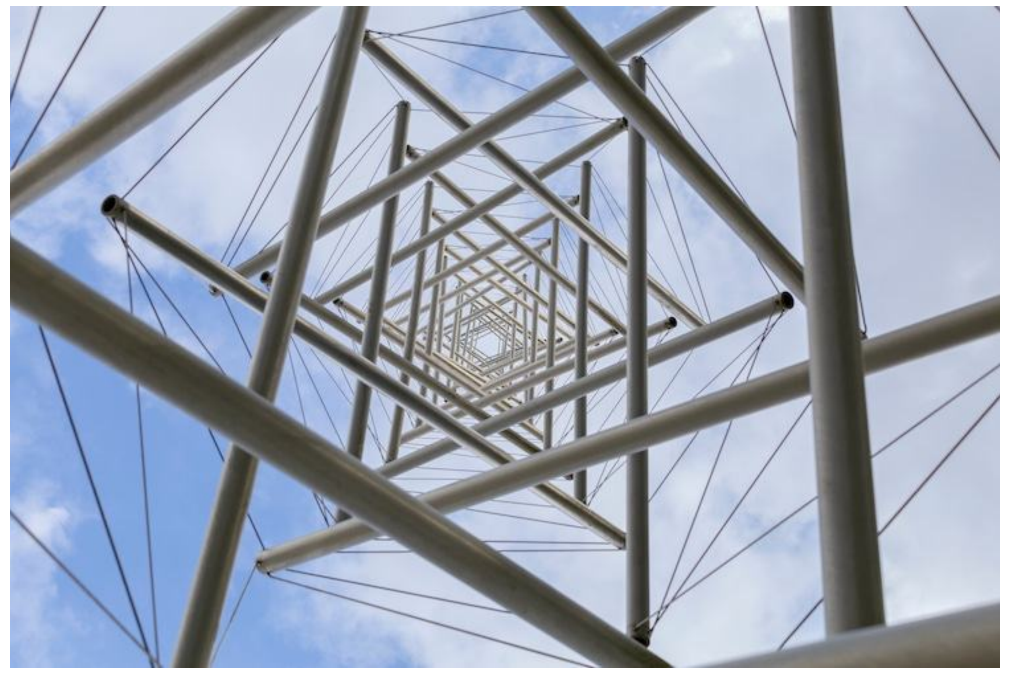

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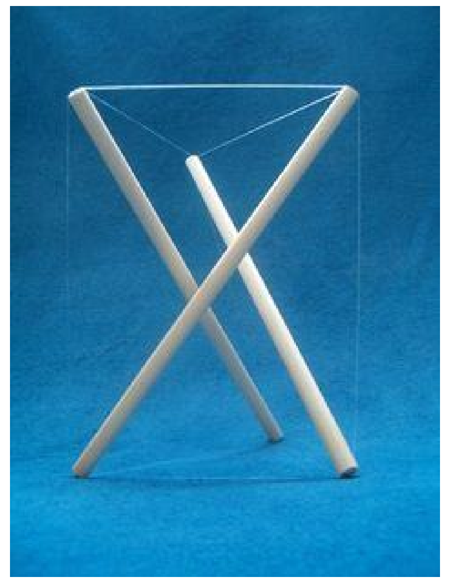
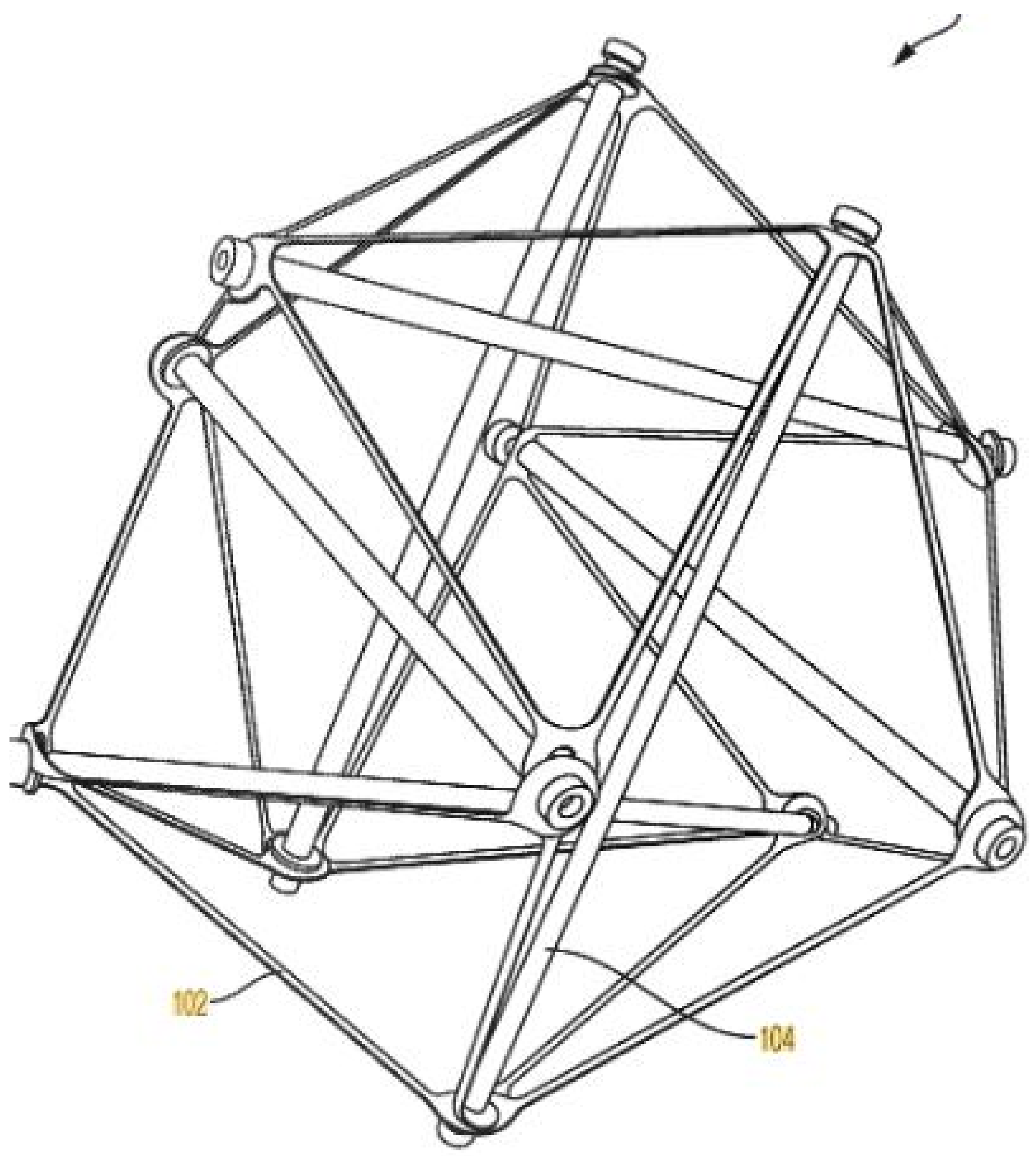


https://www.pinterest.com/pin/using-tensegrity-structure-to-teach-high-school-math--310396599330536949/

Literature review

Relevant patents



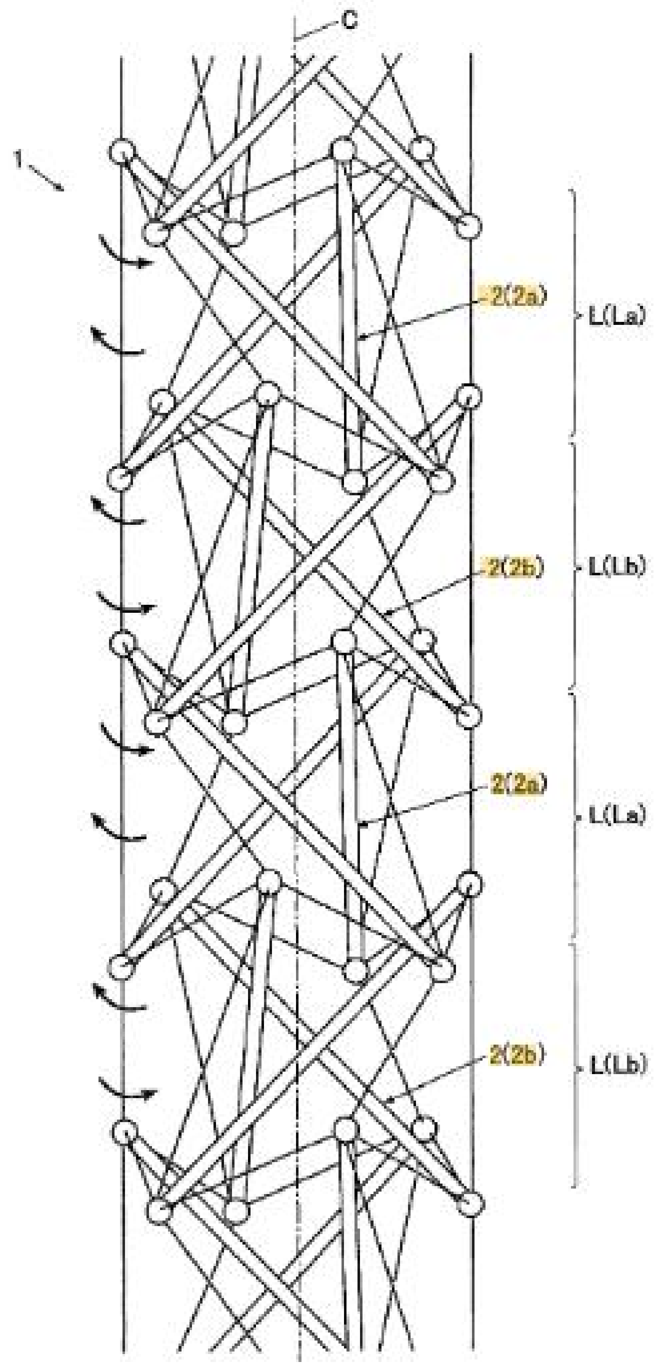


FIG. 6A

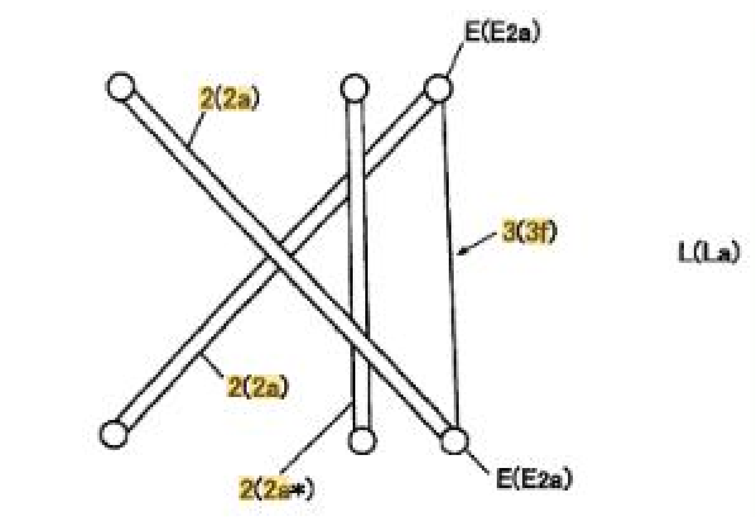
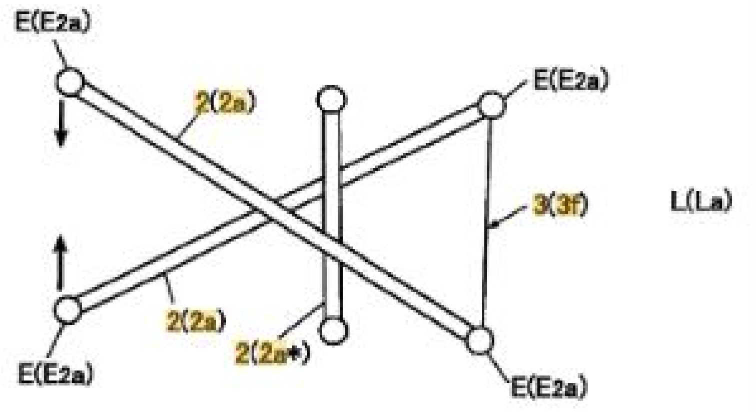


FIG. 6B



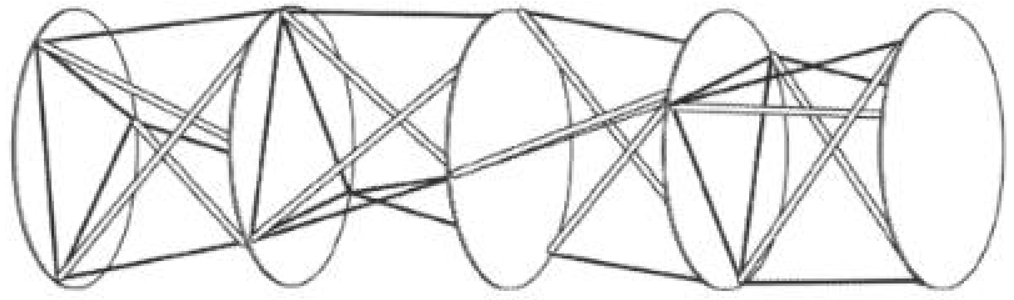


FIG. 1

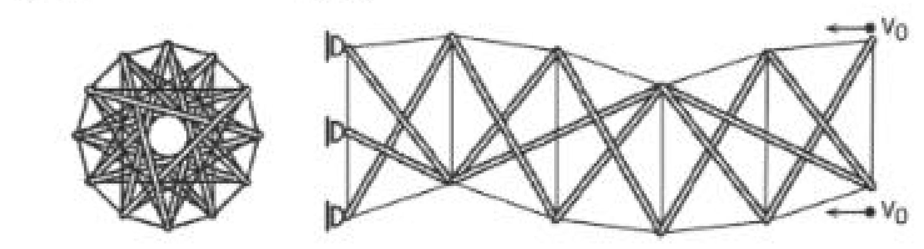


FIG. 2

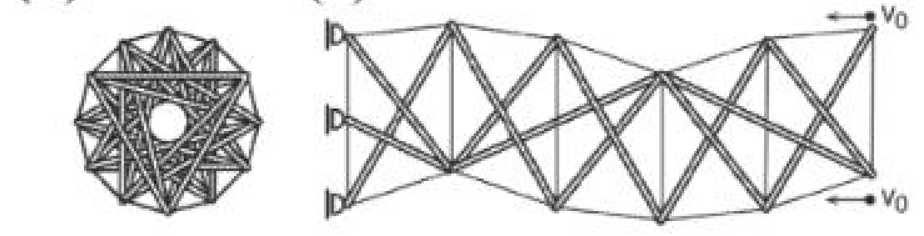
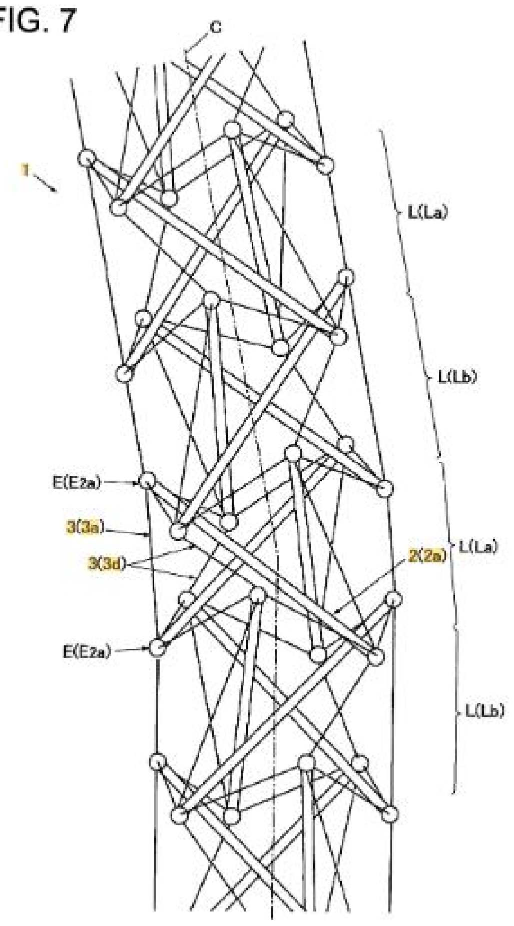
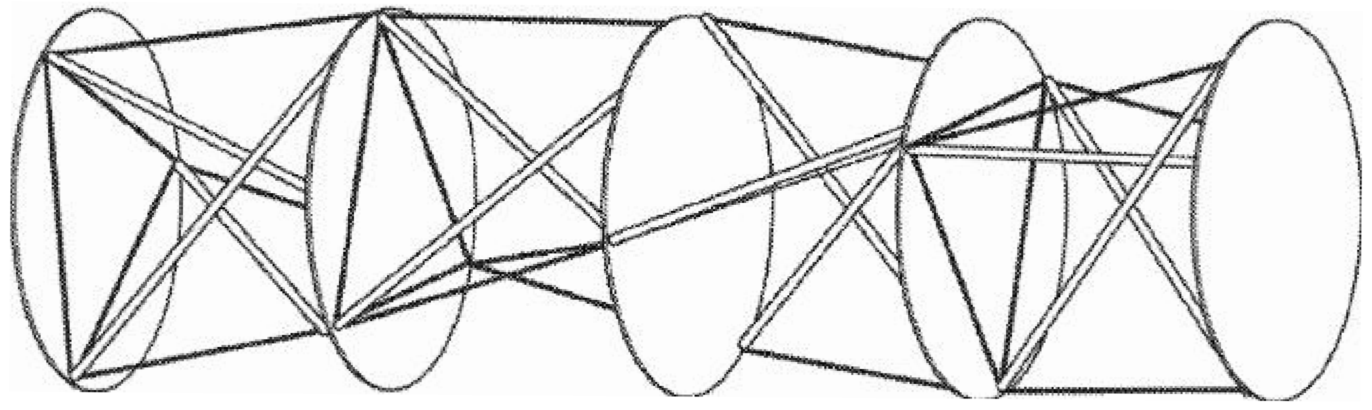
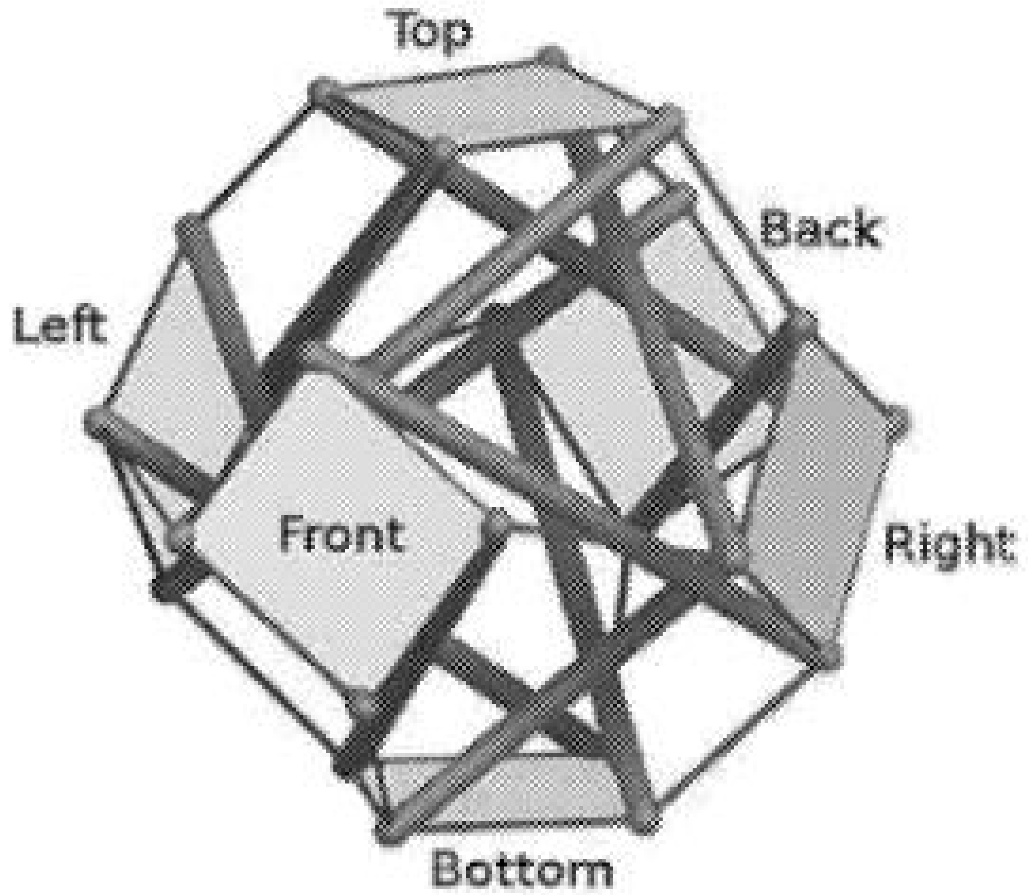


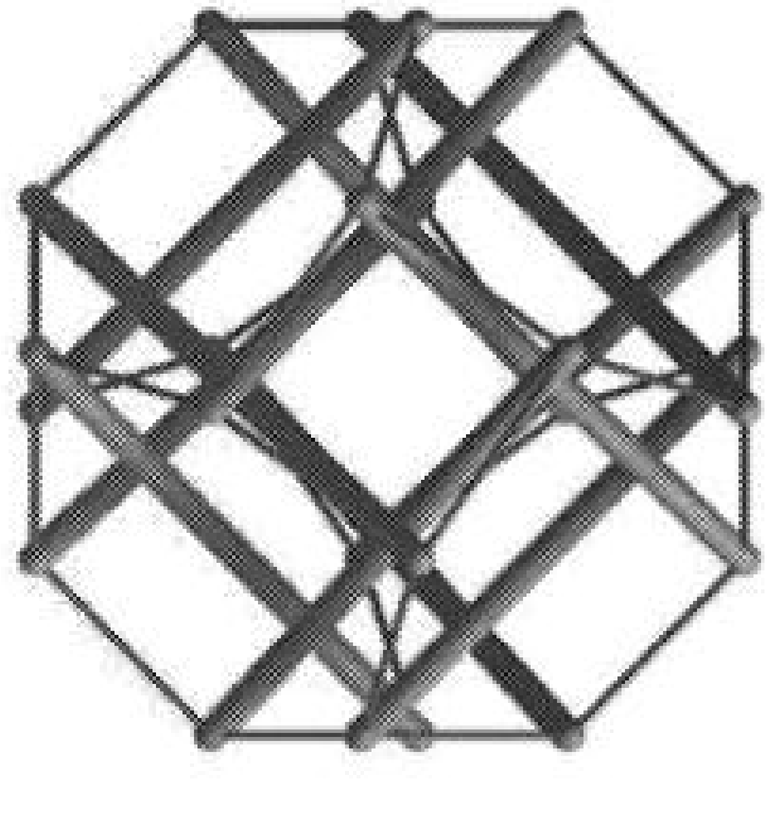
FIG. 7







(A)



(B)

Current feilds of tensegrity

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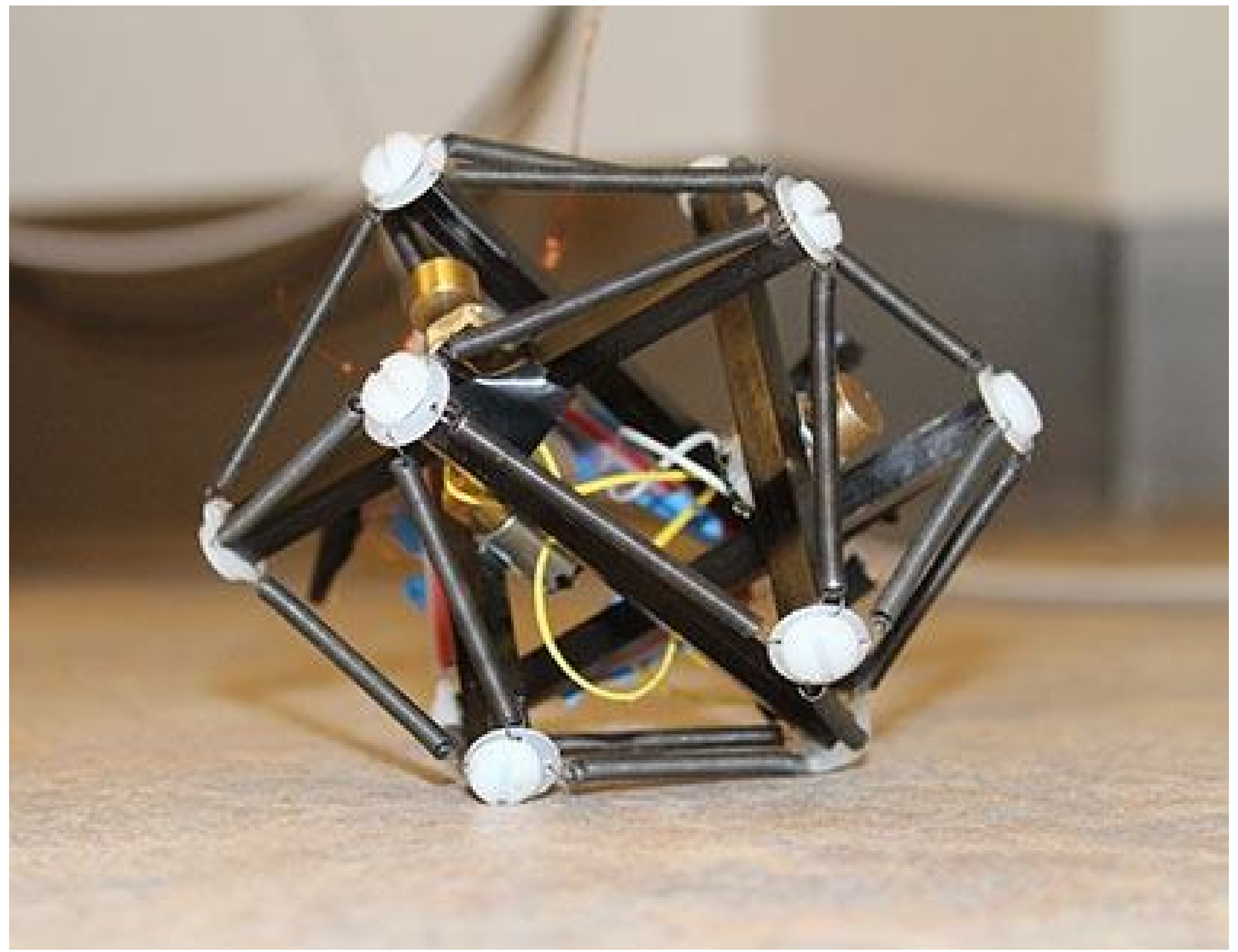
Biomechanics:

Tensegrity principles are being studied in the context of biological systems, including human anatomy and cell mechanics.



Robotics:

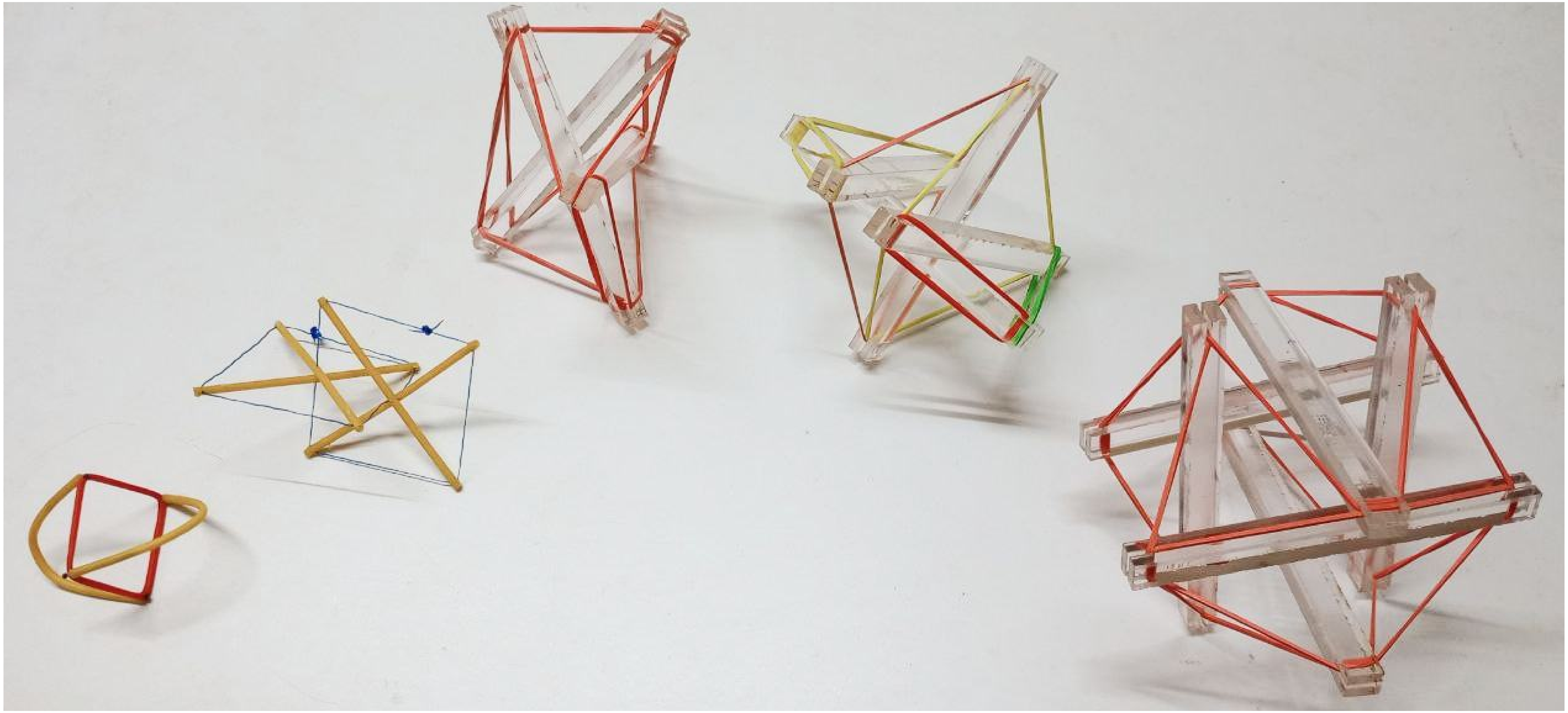
Tensegrity structures have inspired the development of robots that can be lightweight, flexible, and adaptable.

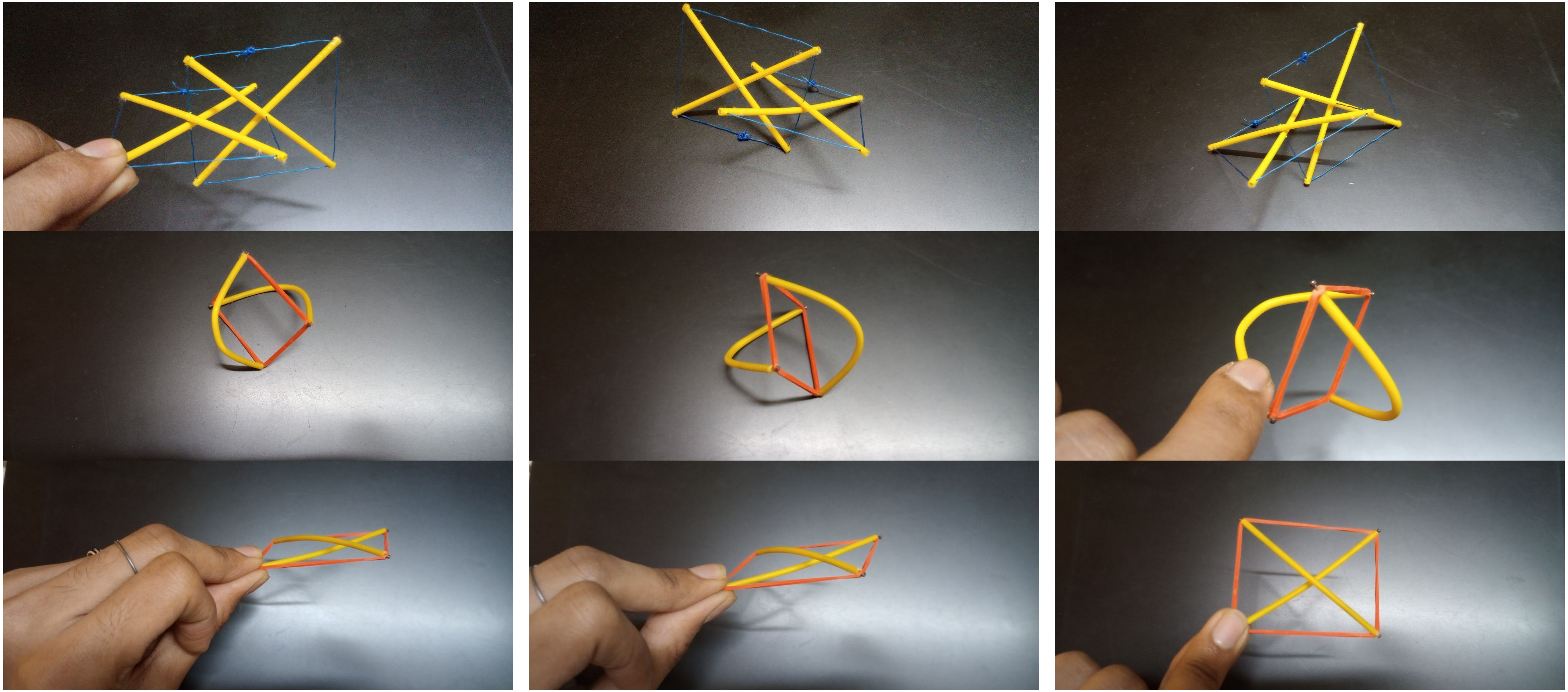
Design enhancement

Implication of the principle of Tensegrity to increase novelty and aesthetics of existing products.

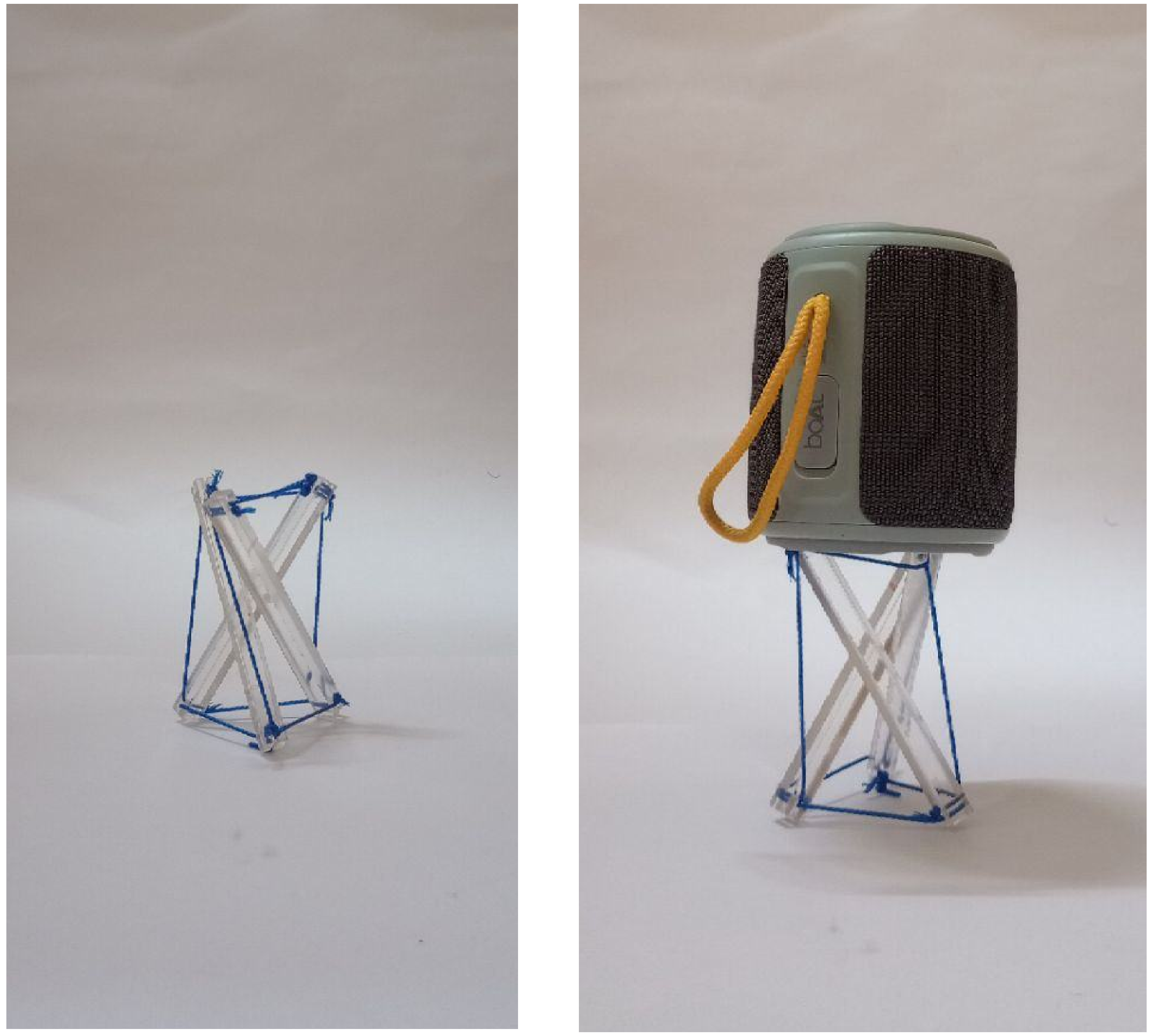
Exploration phase

Creating tensegrity models

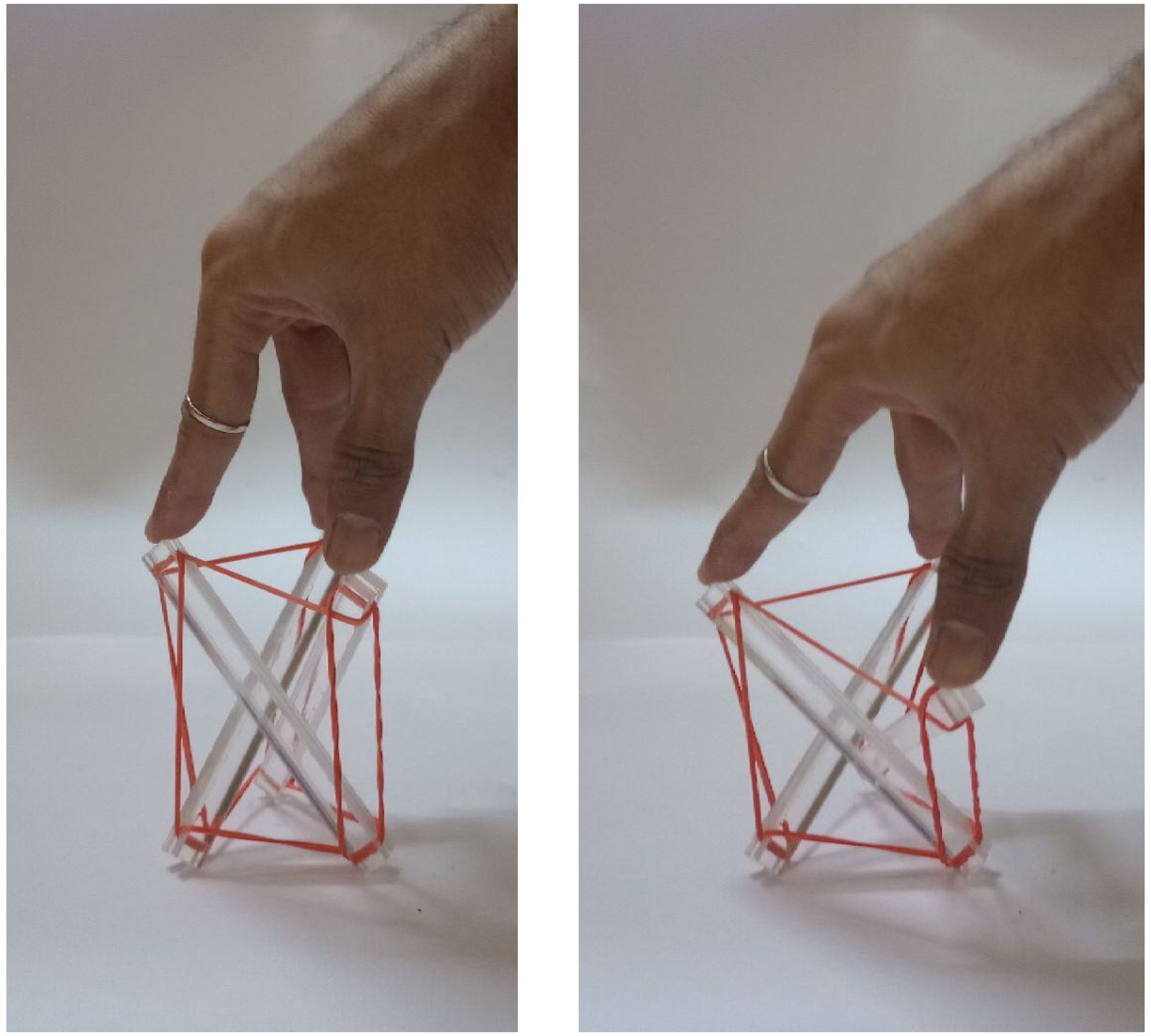




Understanding limitations and potential design opportunities



Ability to act as a solid.



Ability to perform deformations.

Potential for design opportunities

"The experimental phase unveiled the diversity and intricacies of tensegrity structures, showcasing their modularity and material-dependent properties. Flexibility in tension elements allows deformation and restoration. However, the fragility of these structures demands precision in assembly to prevent collapse when altered.

From these experiments emerged the potential for shape manipulation, especially with 'mast' structures. These modular forms offer opportunities for dynamic shape changes, from linear to volumetric, presenting potential avenues for a functional, adaptable design." This version distills the essence of the findings about tensegrity structures and their potential for shape manipulation based on your experimentation.

Key findings

- **Experimental Findings:** Versatility, Flexibility
- **Limitations:** Precision, Fragility
- **Design Opportunities:** Adaptability, Modularity, Maneuverability
- **Experimental Methodology:** Exploration, Fragility Testing, Alteration Testing

Project Scope and boundaries

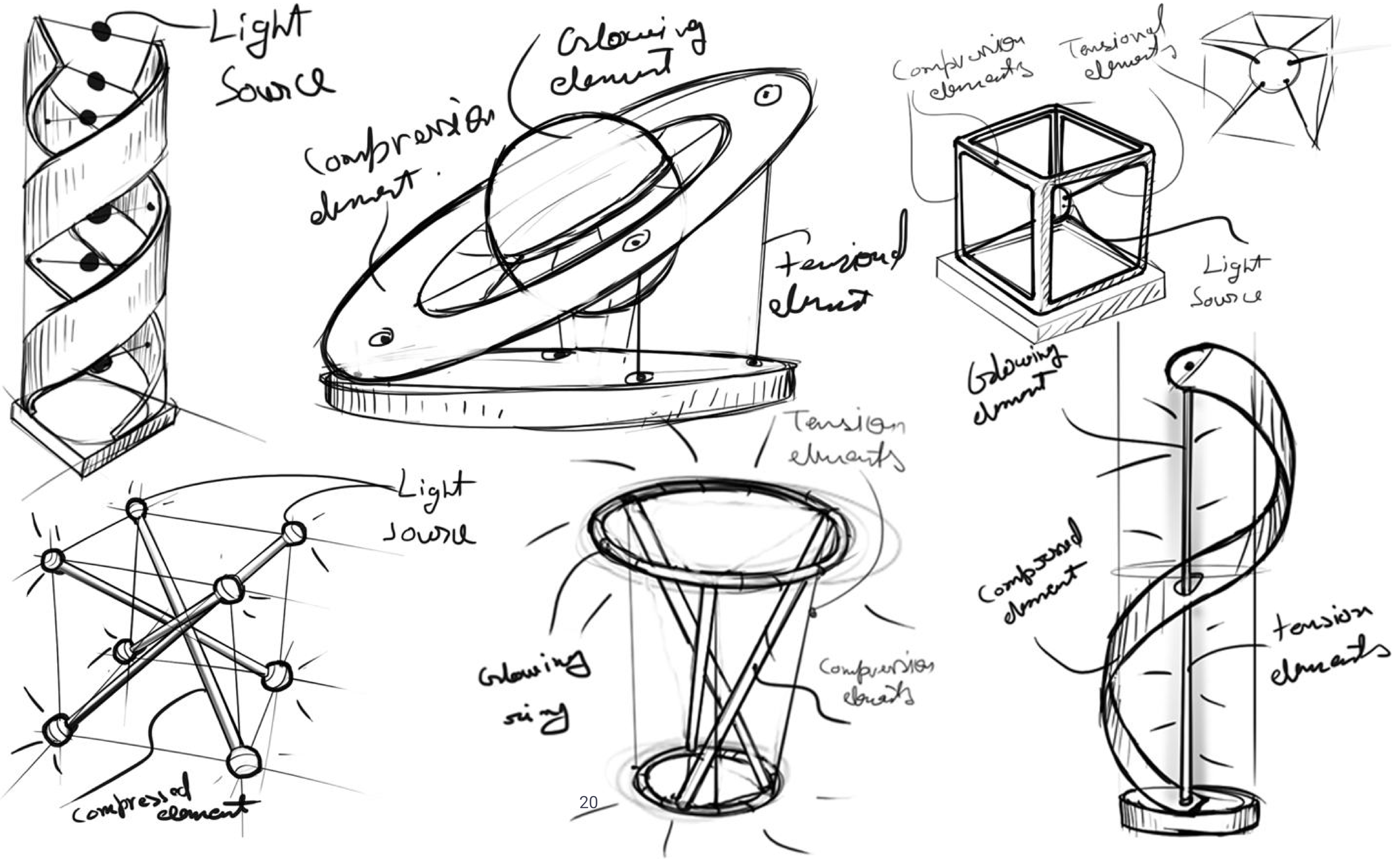
Aim

Design a lamp using specific features of tensegrity.

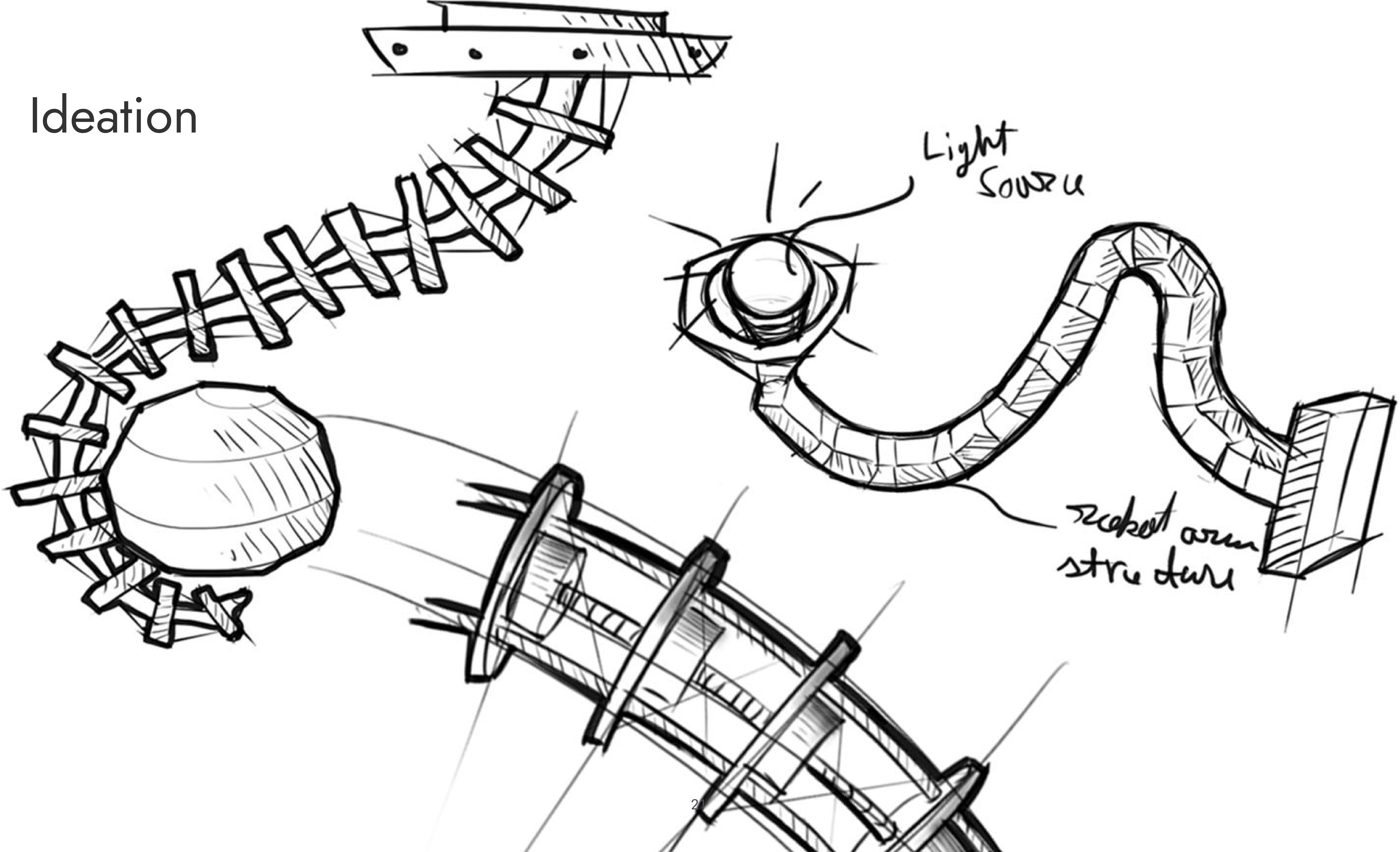
Design constrains

- Mobility
- Control
- Pure mechanical
- Simple

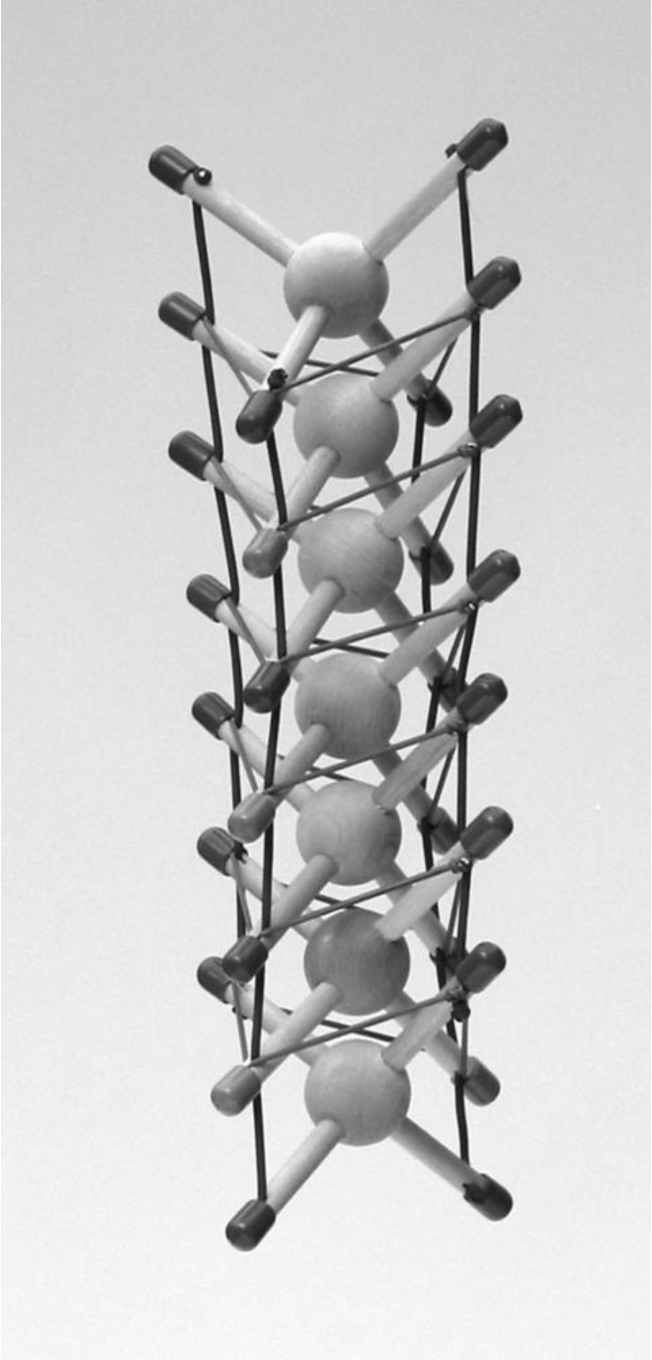
Design concept

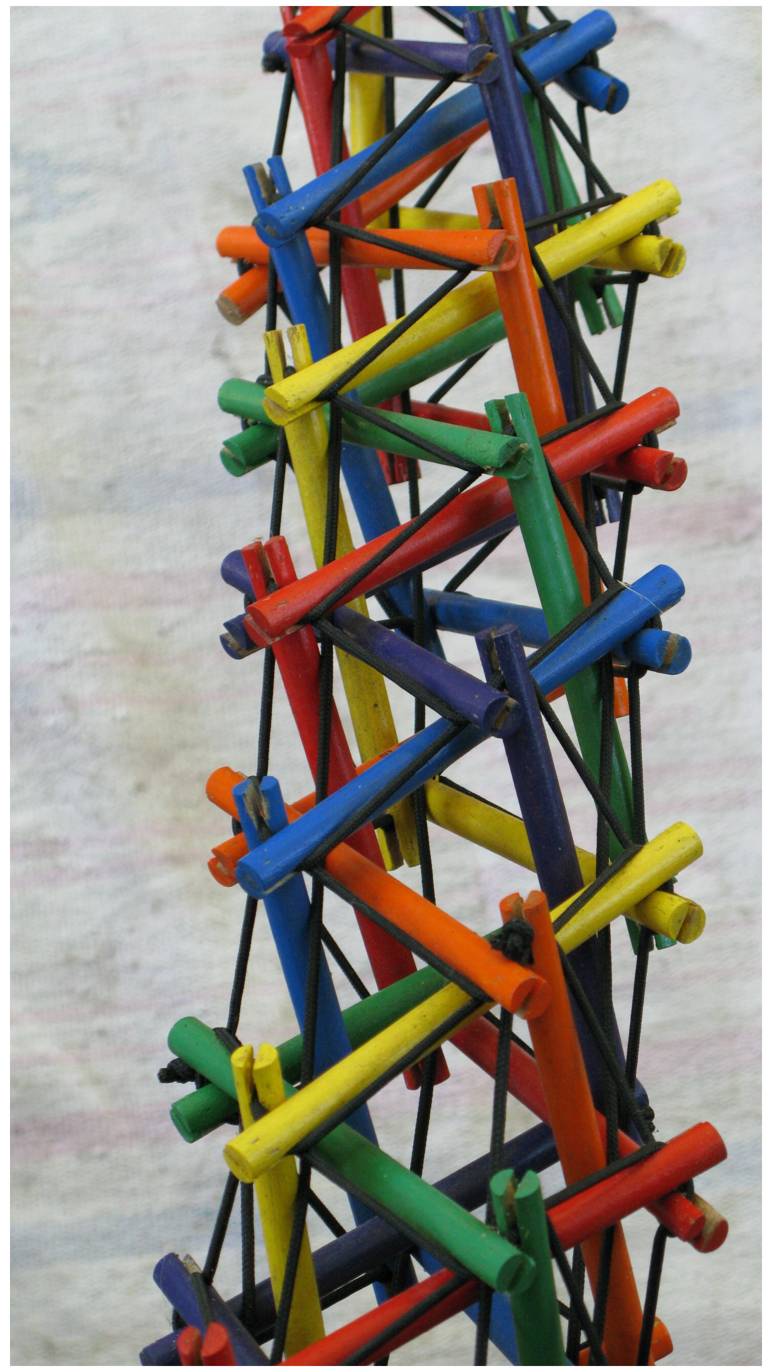
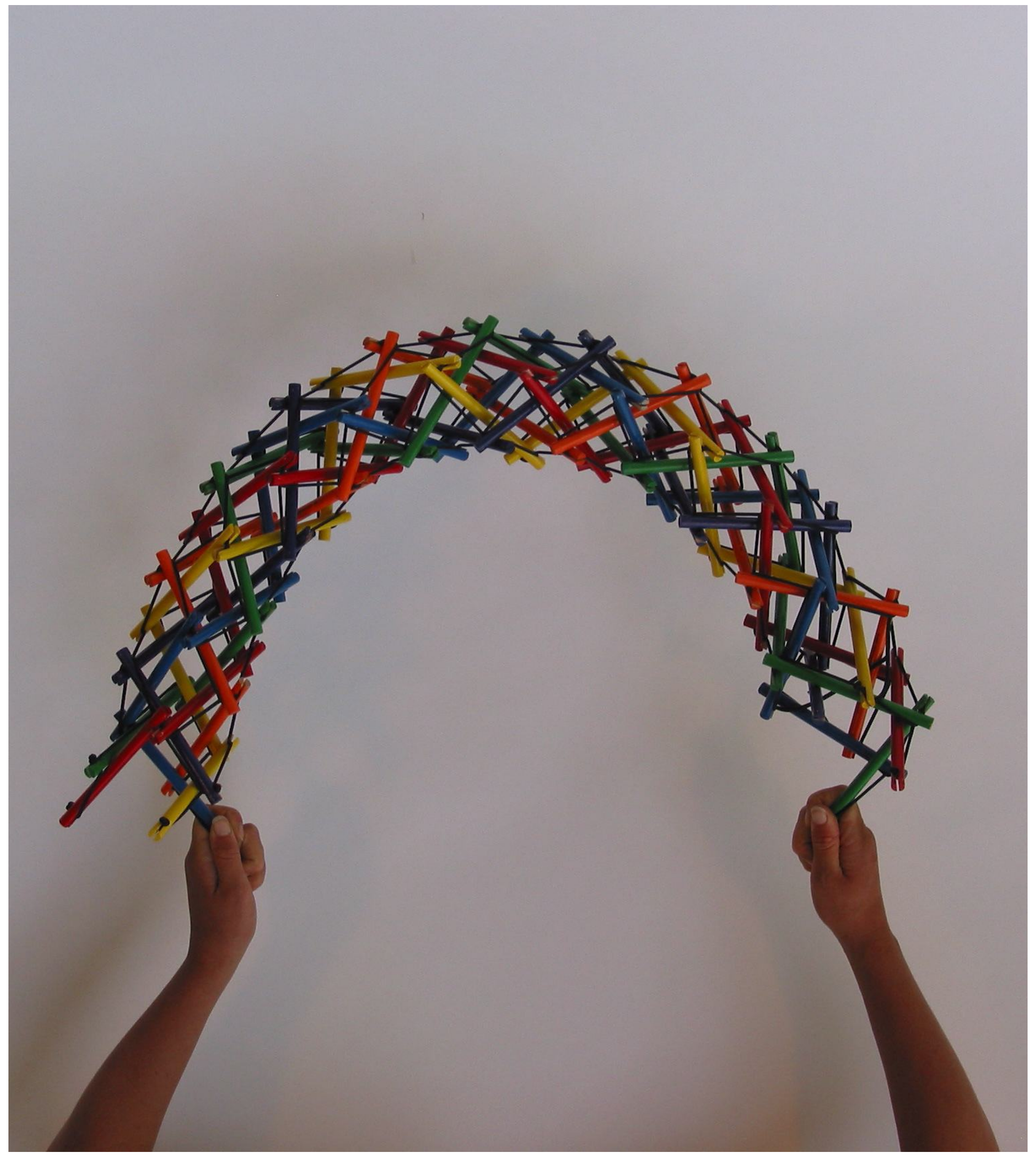
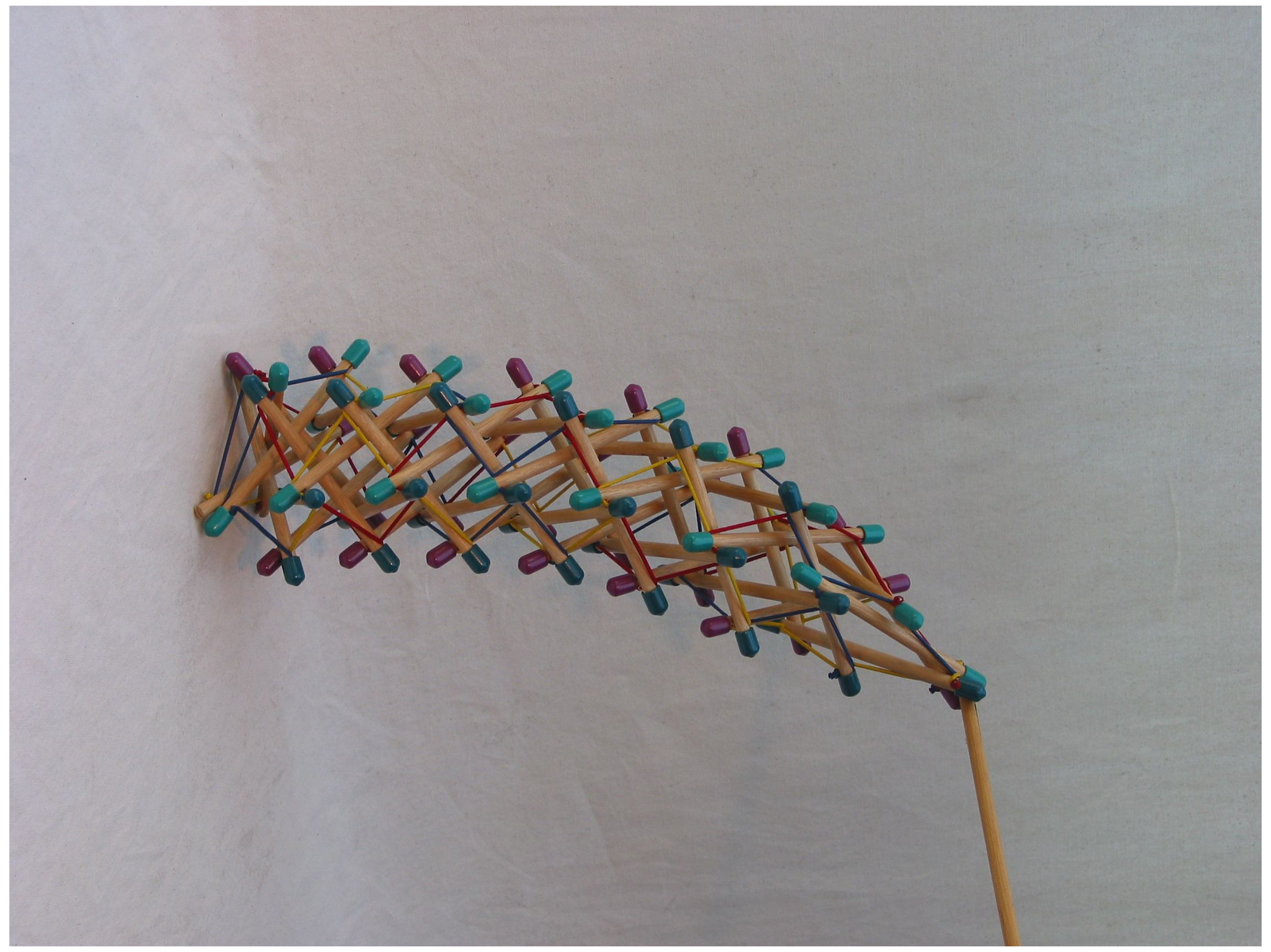
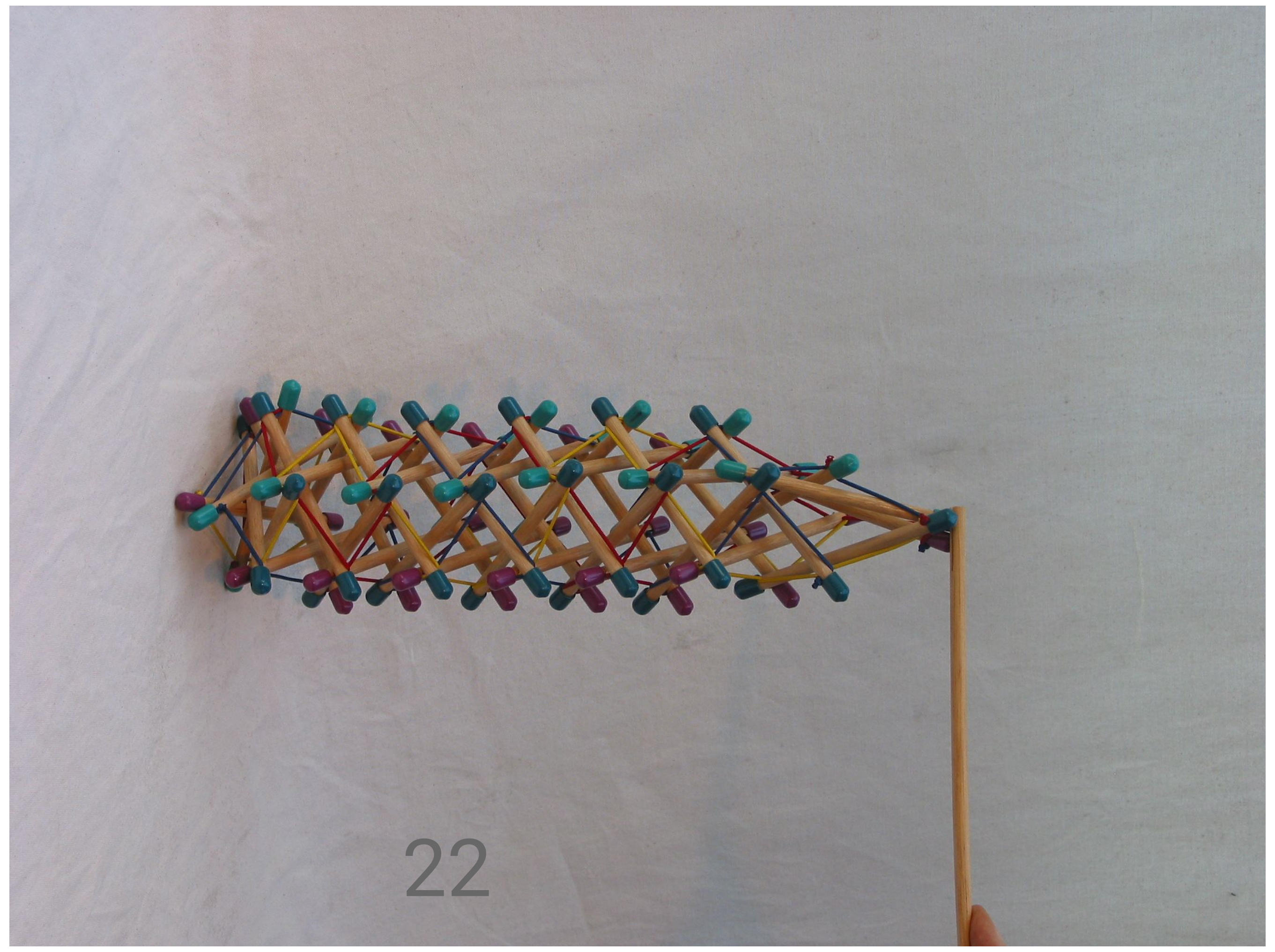


Ideation



Mast structures

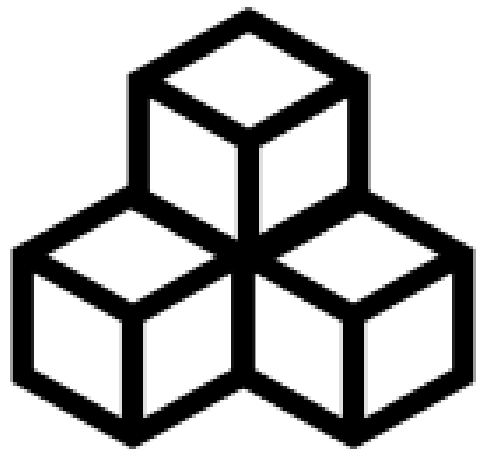


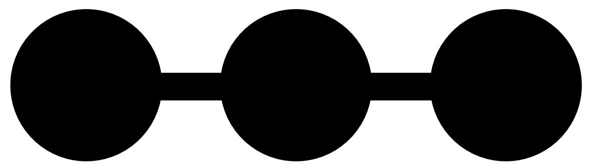

https://intensiondesigns.ca/tensegrity-masts/

Why mast structure?

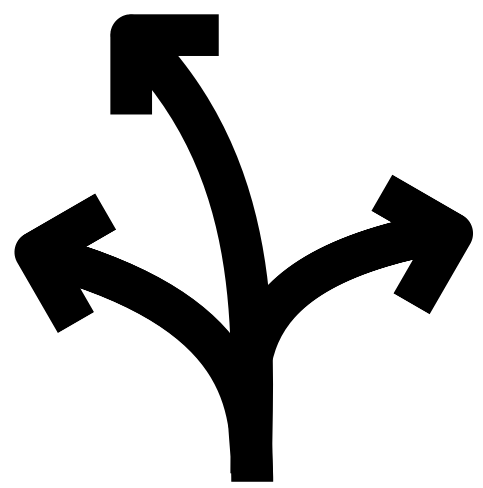
"After establishing the project's aim, I delved into conceptual sketches to explore design possibilities. The mast structure emerged as the optimal choice for further development due to its inherent modularity, linear growth, and arm-like motion. These properties offer a myriad of opportunities, aligning seamlessly with the project objectives. The mast structure's modularity provides flexibility, scalability, and dynamic adjustments, addressing both functional and aesthetic considerations. Its linear growth ensures controlled evolution, while the arm-like motion introduces dynamism and adaptability. This strategic selection positions the mast structure as the central element for the project's subsequent approach, harnessing its unique characteristics to optimize form and function."



Modularity



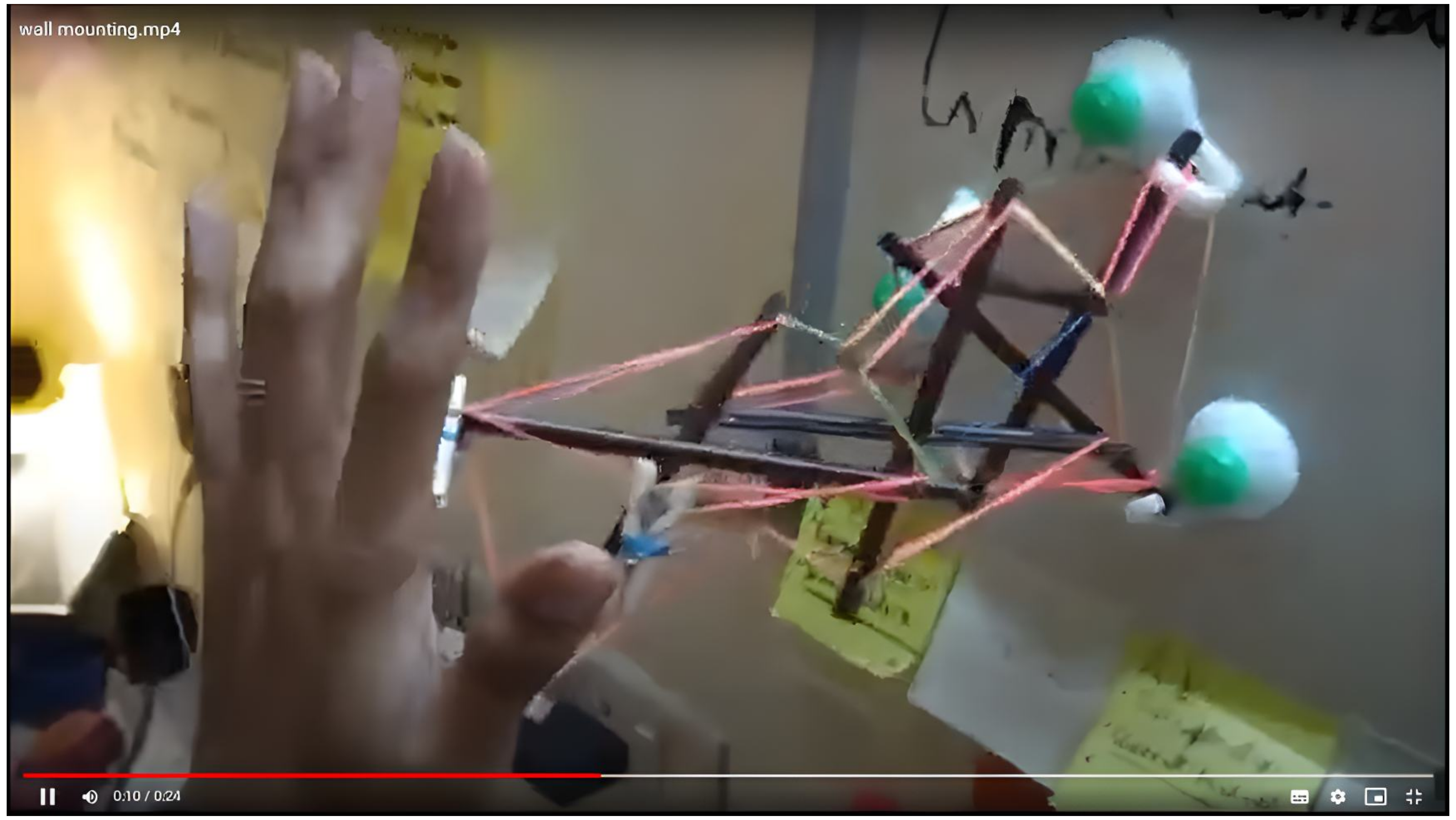
Linearity



Flexibility

Testing 1

- I constructed a mast structure as a practical exploration to comprehend its total functionality. Employing rubber bands as tensional elements and sticks with vertical cuts at the ends, I built the structure, affixing it to the wall using suction-padded hooks. This experimental setup allowed for a tangible understanding of the structure's behavior. The integration of elastic elements not only facilitated smooth movements but also prevented collapse even under significant deformations. The strategic use of suction-padded hooks ensured stability during mounting, contributing to a comprehensive grasp of the mast structure's capabilities and its dynamic response to external forces.



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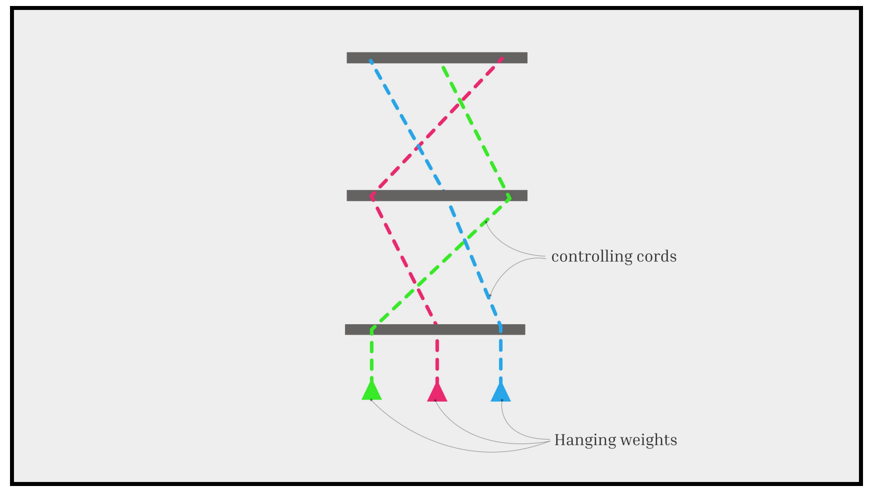
Mechanism and functionality

String Control Mechanism: Shaping the Dynamics of the Mast

- "To realize the functionality of my concept, I've devised a method to control the form of the mast structure using a straightforward string system. This system involves attaching a string at the top corner of the end elements on the structure, which then threads through one end of every other stick in a distinct path, determined by the number of elements in each unit. The strings are organized into groups, each controlling a specific segment of the structure. By manipulating these string groups separately, I can induce a bend on one side of the structure. This granular control allows me to shape the entire structure dynamically, bending it in any direction or contracting it as a whole. The strings, manually controlled, serve as a versatile mechanism for achieving a range of forms and functionalities in the tensegrity lamp design."

1.



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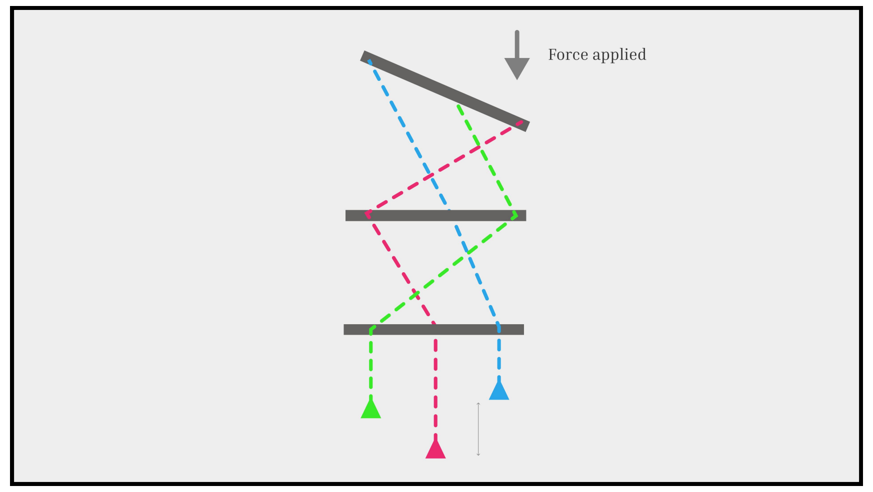

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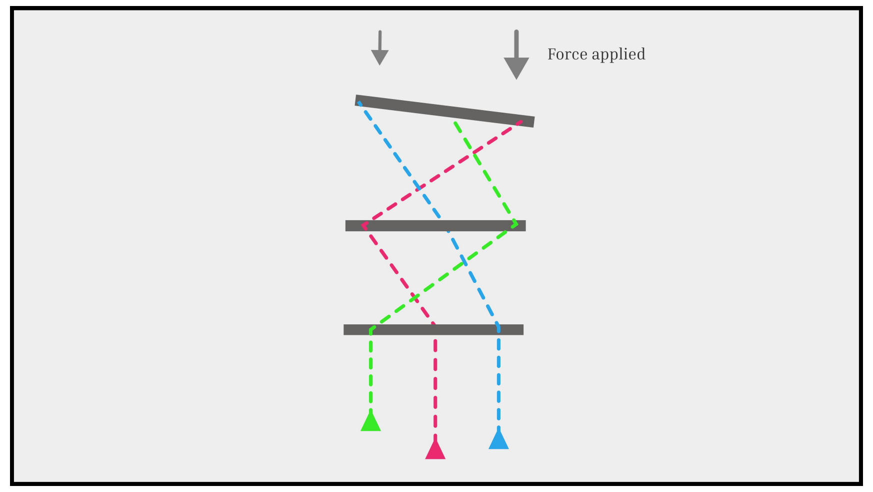

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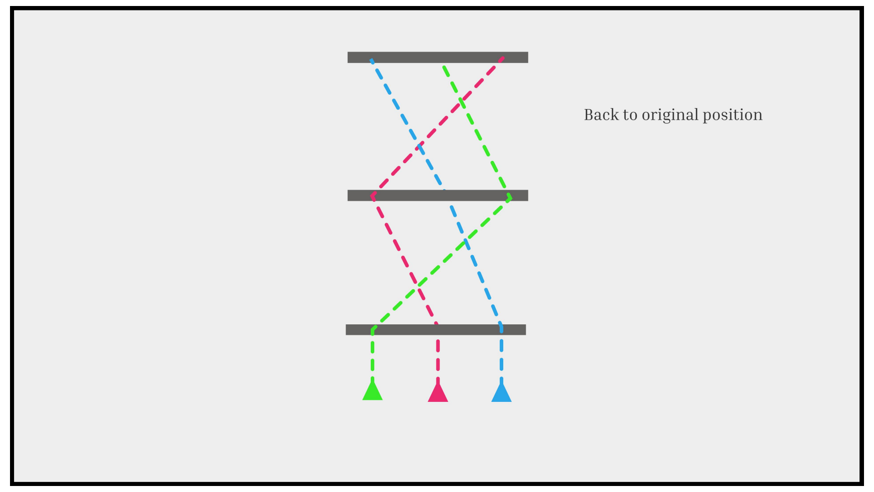
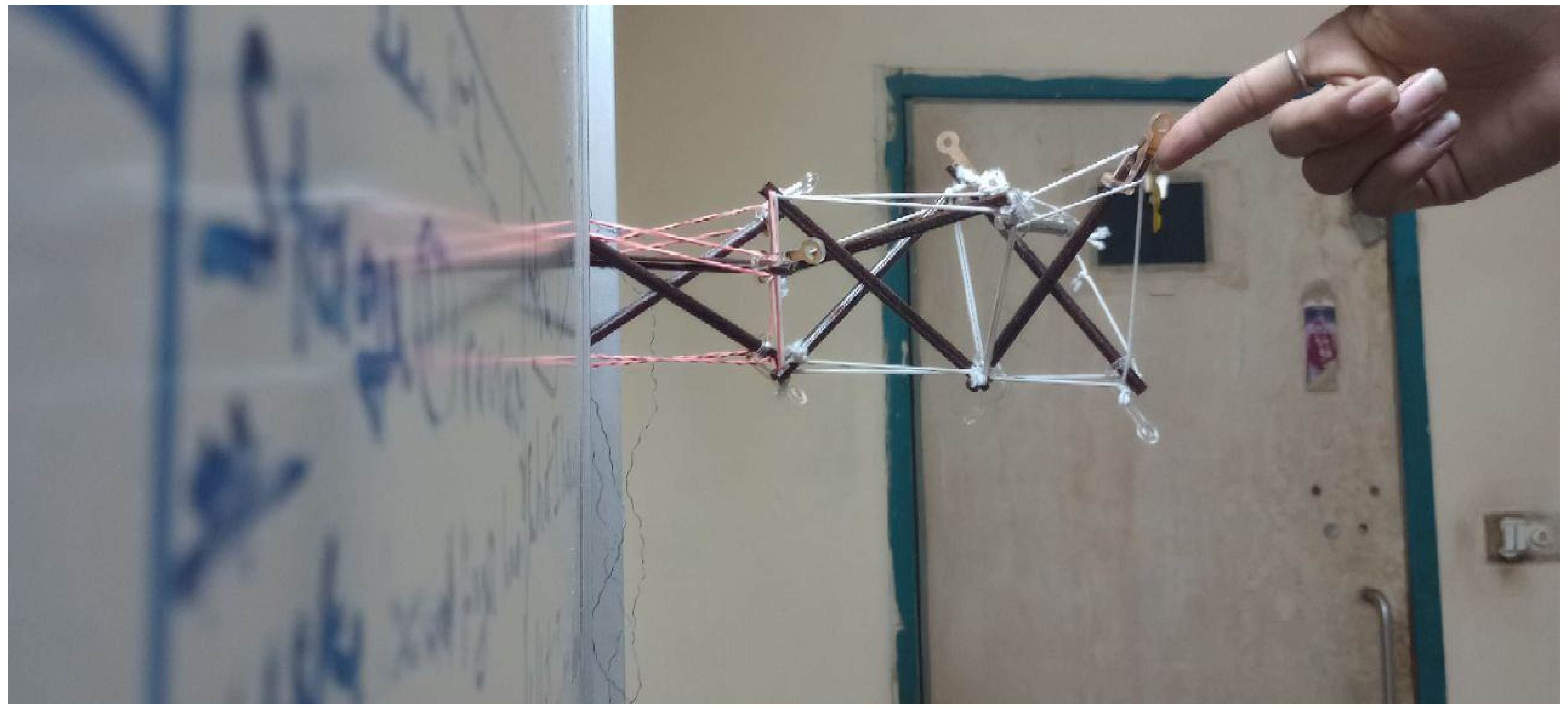


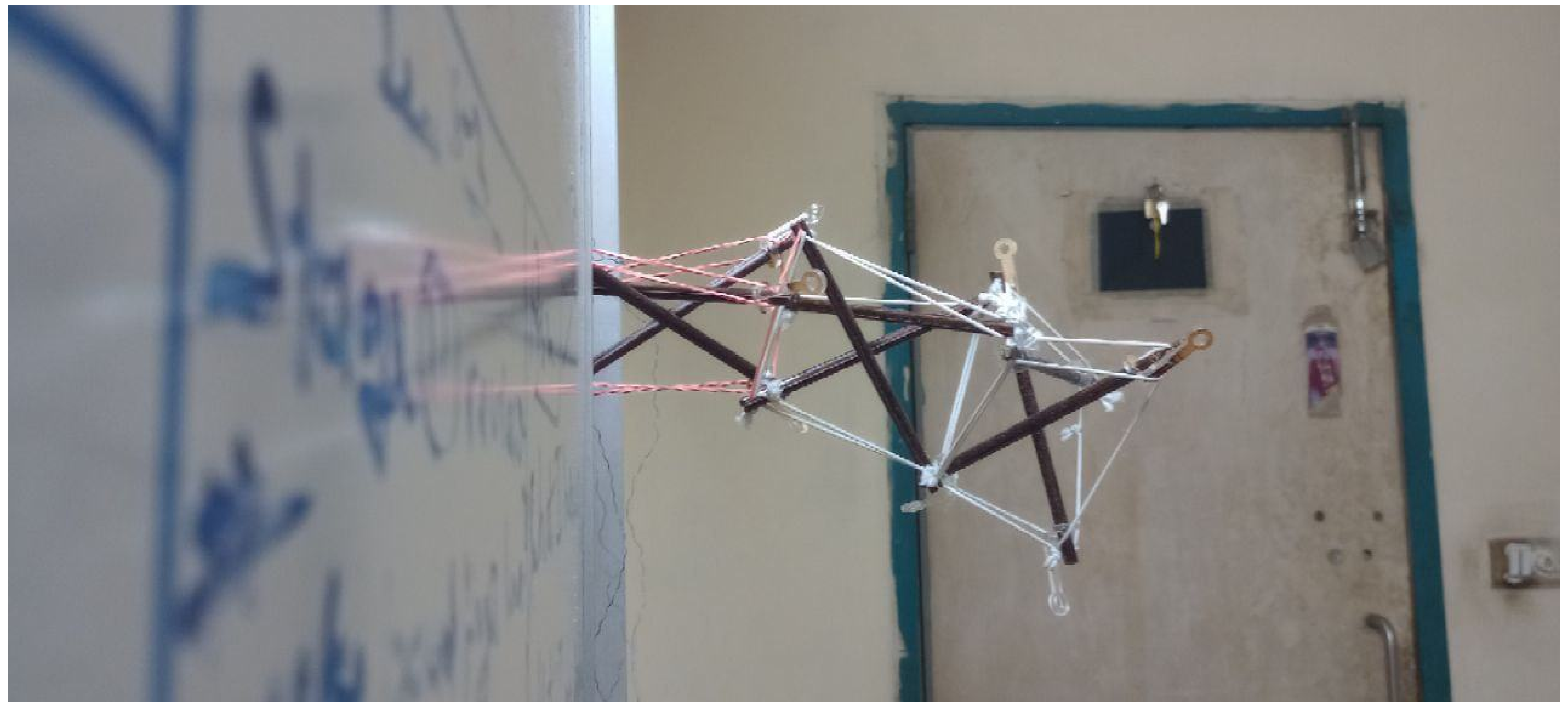
Structural Analysis

Testing 2

During structural testing on the mast structure, constructed using identical sticks with cuts at the ends and secured by rubber bands in those incisions, a critical flaw in the design became apparent. As I attempted to mount the structure on the wall, it started to collapse under its own bending moment.

Notably, this occurred even before adding lighting or other elements to the structure, revealing an inherent weakness. The primary issue lies in the use of tension strings (elastic bands) as joints rather than solid elements. The tension string joints tend to twist, compromising the stability of the entire structure.



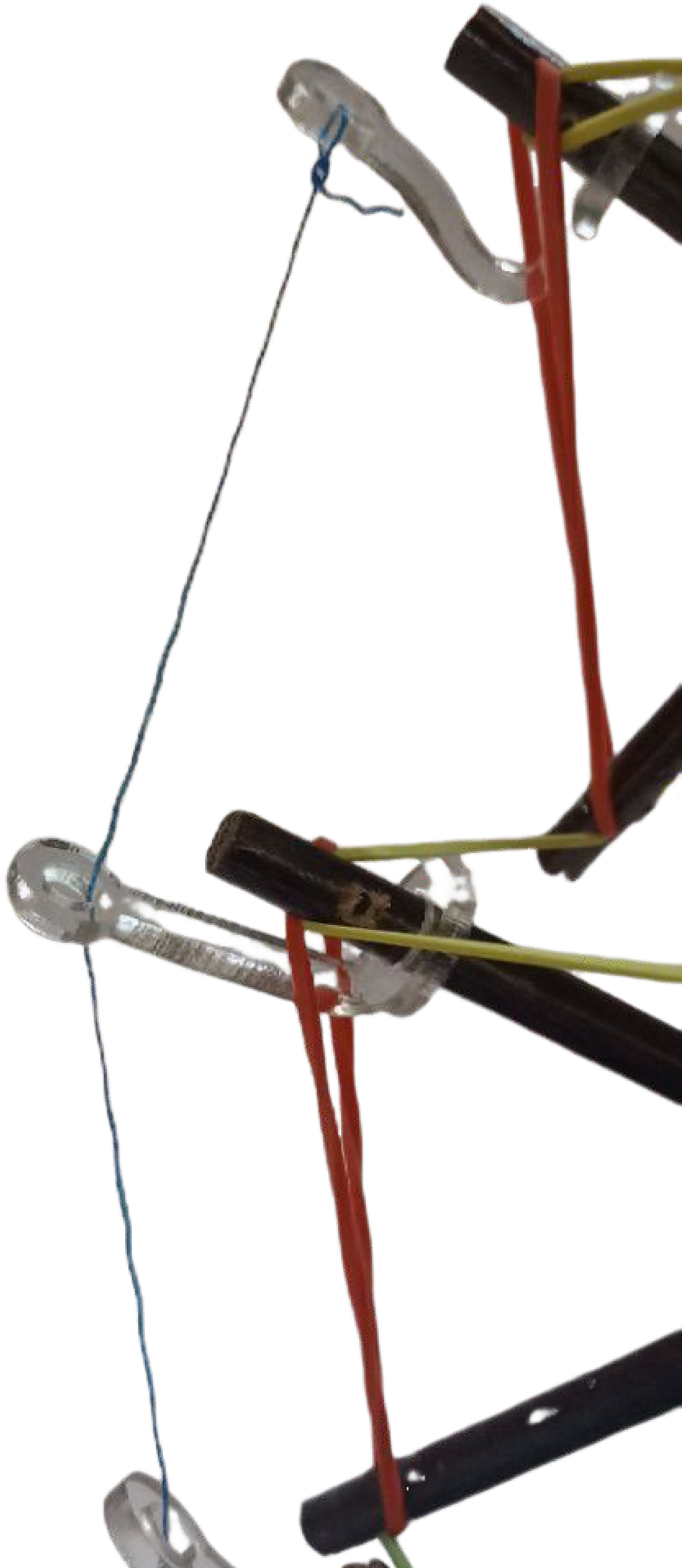


Testing 2

This design flaw becomes more pronounced when attempting to extend the structure beyond a certain limit, leading to the imminent collapse of the entire form. Addressing this challenge requires reconsideration of the joint design to enhance stability and the capacity to support additional elements.

Key findings

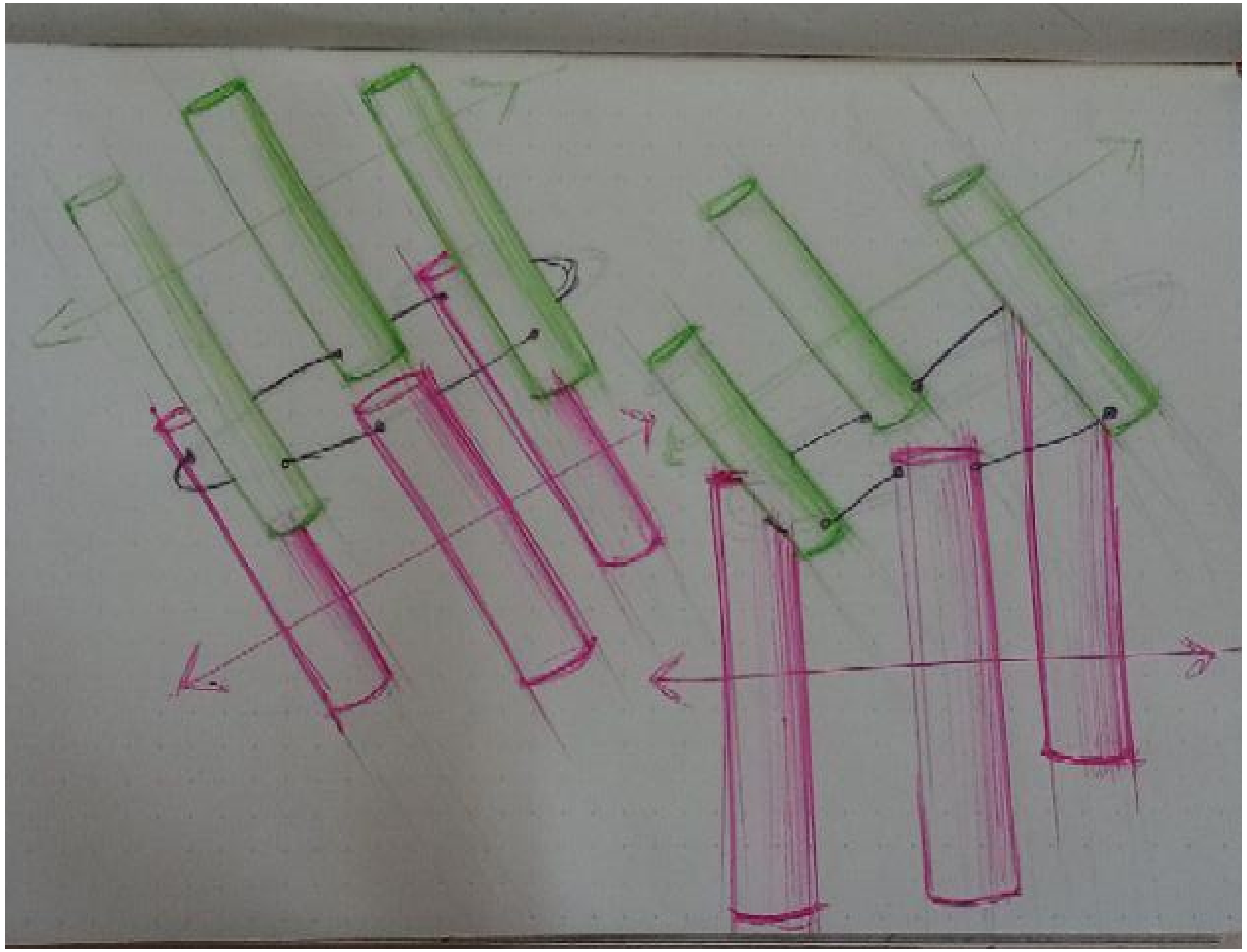
- Flaw Identification during Structural Testing:
- Collapse under Bending Moment:
- Early Weakness Revelation:
- Issue with Tension Strings as Joints:
- Twisting Tension String Joints:
- Pronounced Flaw during Extension:
- Imminent Collapse of Extended Structure:
- Addressing the Challenge:



Problems solving

Failure detection

1. Collapse during Wall Mounting:
2. The structure collapsed under its own bending moment during an attempt to mount it on the wall.
3. Pre-existing Flaw without Additional Elements:
4. Collapse occurred even before adding lighting or other elements to the structure.
5. Issues with Tension String Joints:
6. Twisting of tension string joints compromised the stability of the entire structure.
7. Limitation on Structure Extension:
8. Attempting to extend the structure beyond a certain limit resulted in the collapse of the entire lamp.



Possible solutions

1. **Strengthening Joints:**
    a. Considered improving tension force in the strings to enhance structural sturdiness.
    b. Increased tension makes the structure more solid but compromises ease of motion.

2. **No Elastic Elements Approach:**
    a. Explored removing elastic elements and using a controlled mechanism on each string end.
    b. This approach adds weight and complexity to the structure

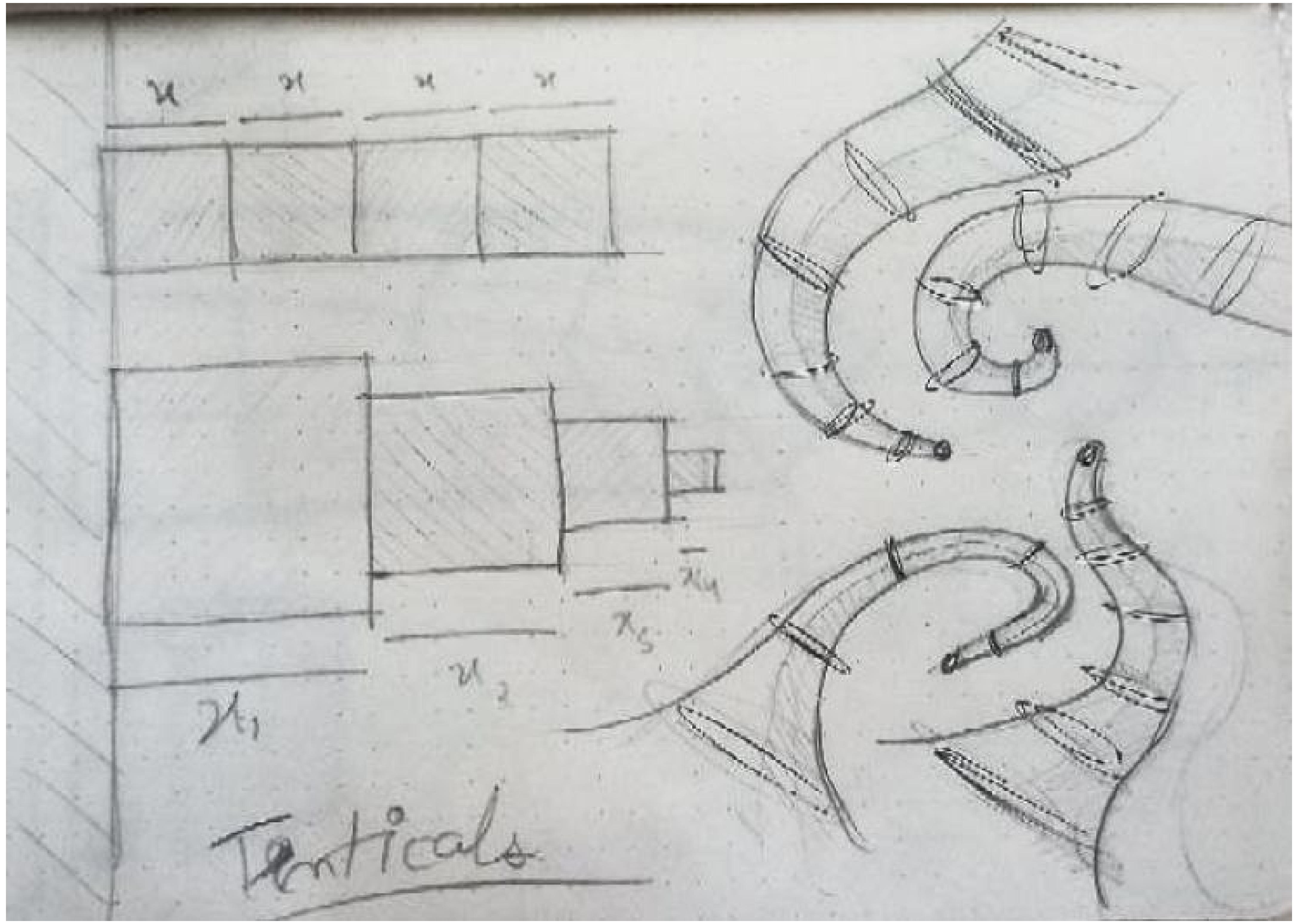
4. **Increasing Number of Elements:**
    a. Considered increasing the number of elements per unit and using more units closely.
    b. This approach risks creating a cluttered and messy appearance, conflicting with the desired minimalist aesthetic.

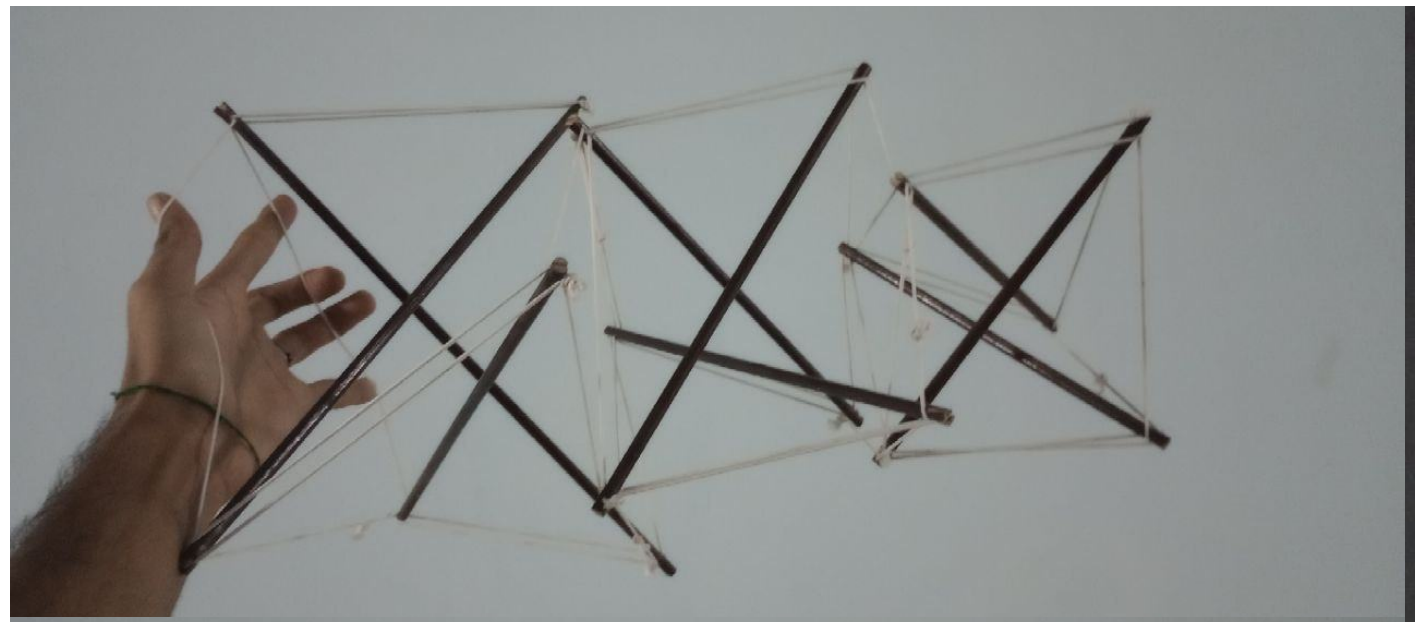
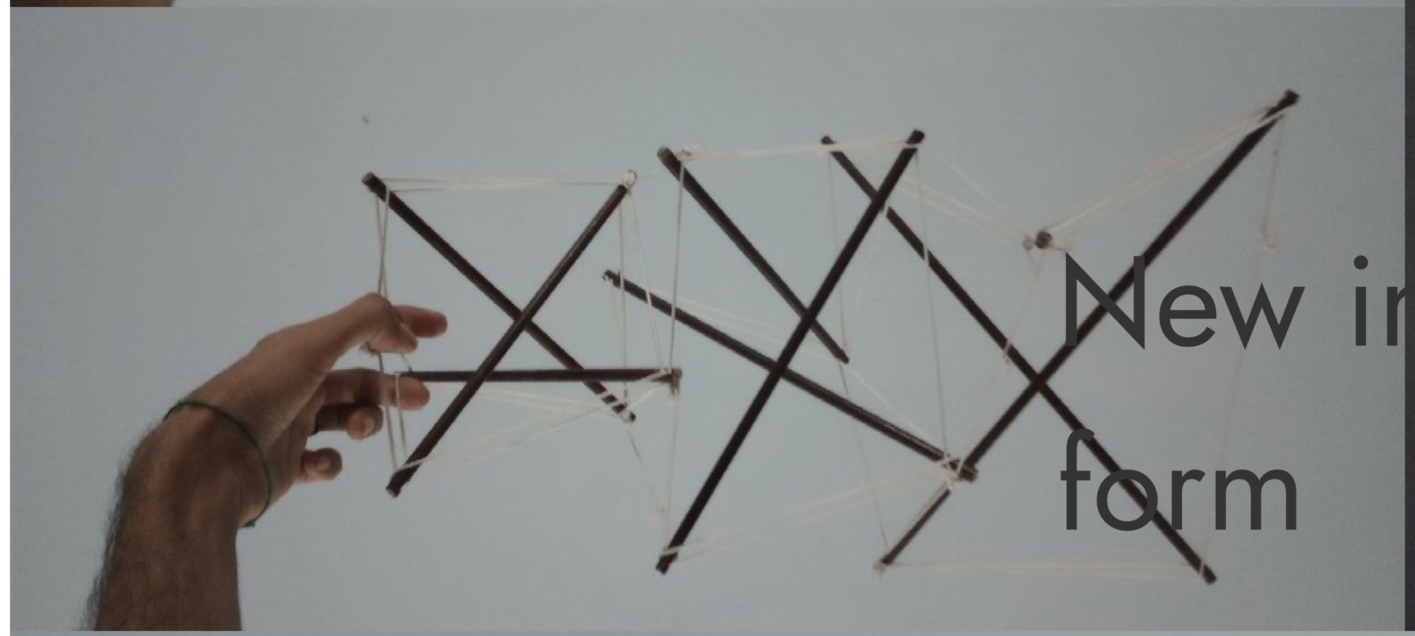
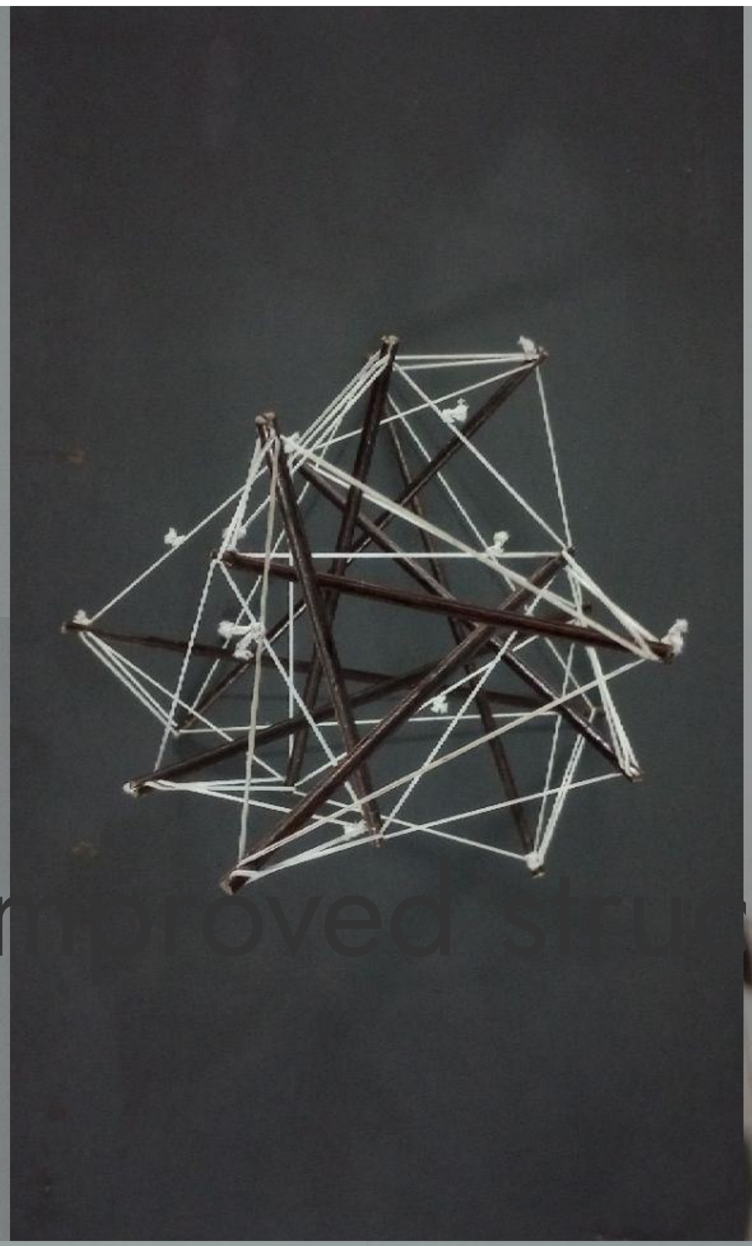
5. **Gradual Change in Size:**
    a. Explored the possibility of introducing a gradual change in size at each step of the mast structure.
    b. Aimed to reduce the bending moment and introduce a more dynamic form to the product.
    c. This approach seeks to avoid a constant linear structure, providing potential for enhanced stability and visual appeal.

Structural Analysis 2

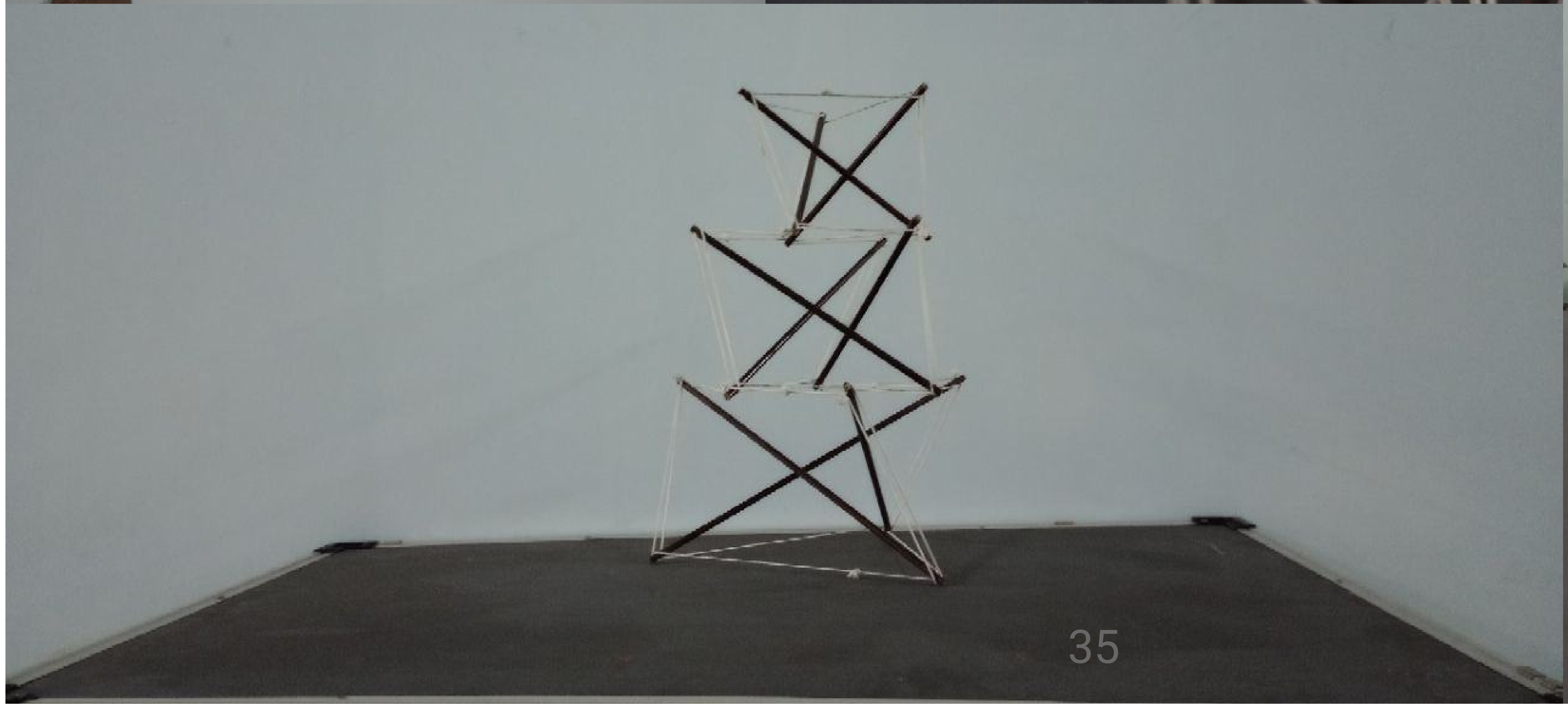
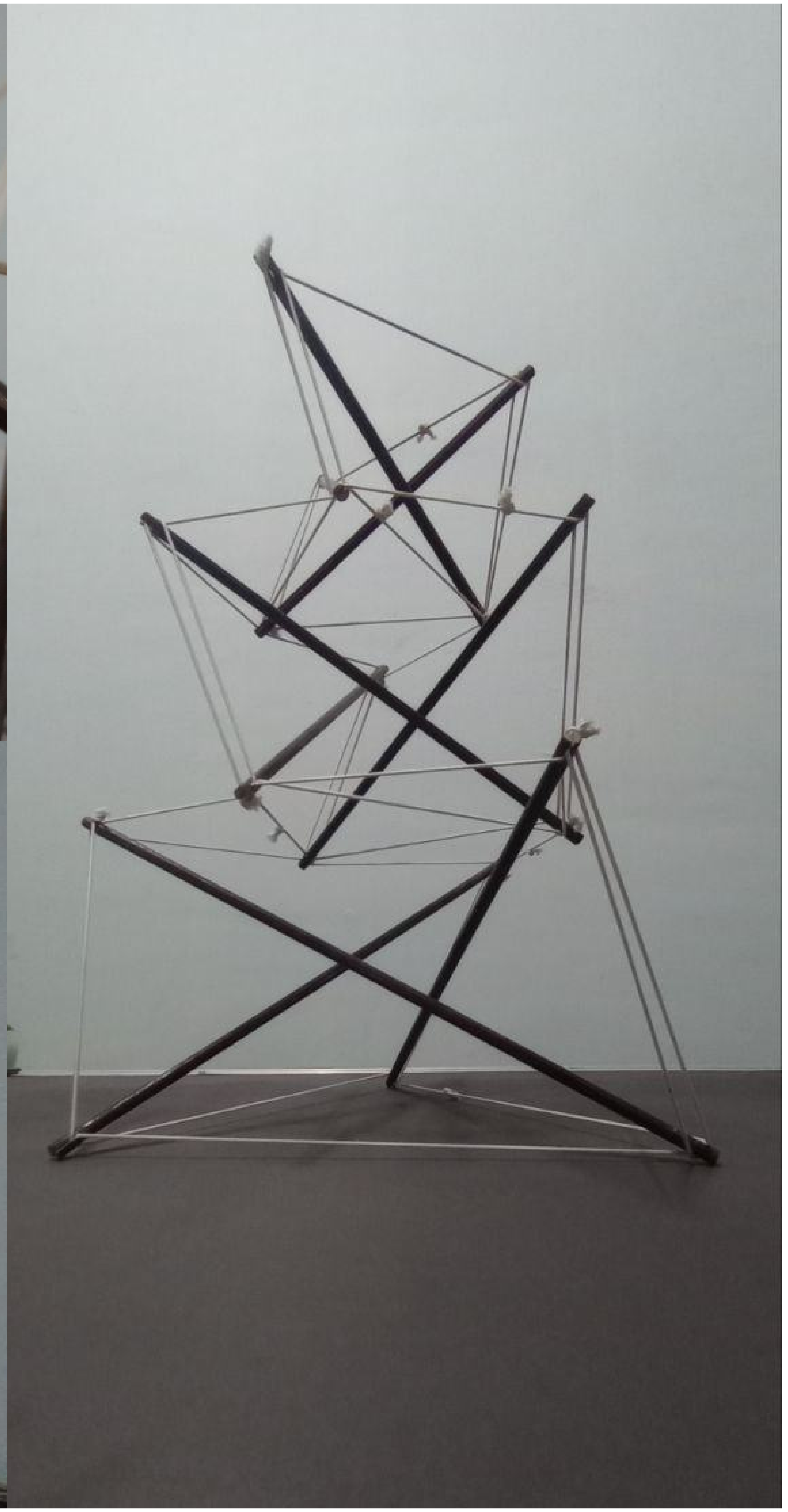
New improved structure

To address the issue of loose joints, I devised a solution by altering the shape of each unit. The chosen modification involves a systematic reduction in the overall scale of unit size by 0.75 times with each subsequent unit. This progressive regression results in a tapered structure reminiscent of an octopus tentacle. The intentional tapering serves to reduce mass at the end points of the structure, thereby enhancing overall structural strength. This structural adjustment aims to eliminate any potential unwanted bending in its form and fortify the structure against weaknesses, contributing to a more robust and stable configuration.



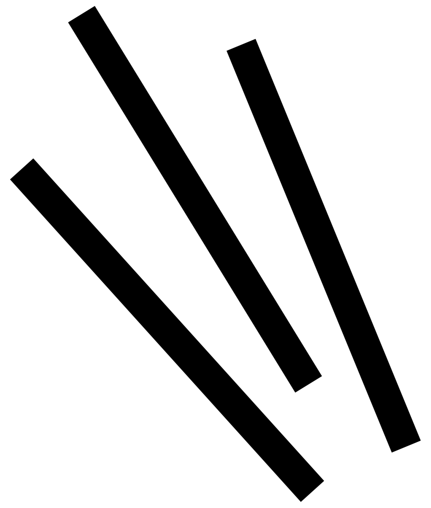





New improved structure form

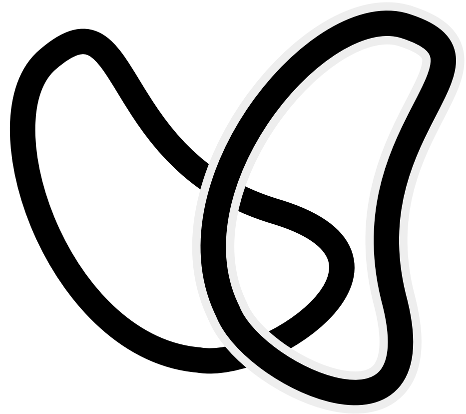
Final design 1

Structural elements involved



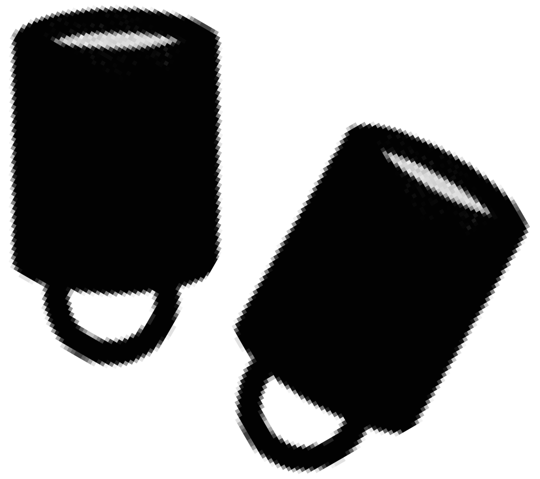
Compression Element (Sticks):

- Sticks organized in groups of three constitute one unit.
- Each subsequent unit follows a 0.75 times reduction in length.
- The gradual reduction in size at each step aims to reduce the bending moment and introduces a dynamic form to the structure.



Elastic Elements:

- Elastic elements provide tension throughout the structure.
- Elasticity is tailored to the specific needs of individual elements in the structure.
- These elements contribute to maintaining the tensegrity equilibrium and overall stability.



Caps:

- Caps are positioned at both ends of every stick in the structure.
- They serve a dual purpose of securing elastic bands and facilitating the passage of control cords.
- Control cords pass through the caps, enabling the manipulation of individual string groups for dynamic shaping and control of the entire structure.

Aesthetic and Design Elements

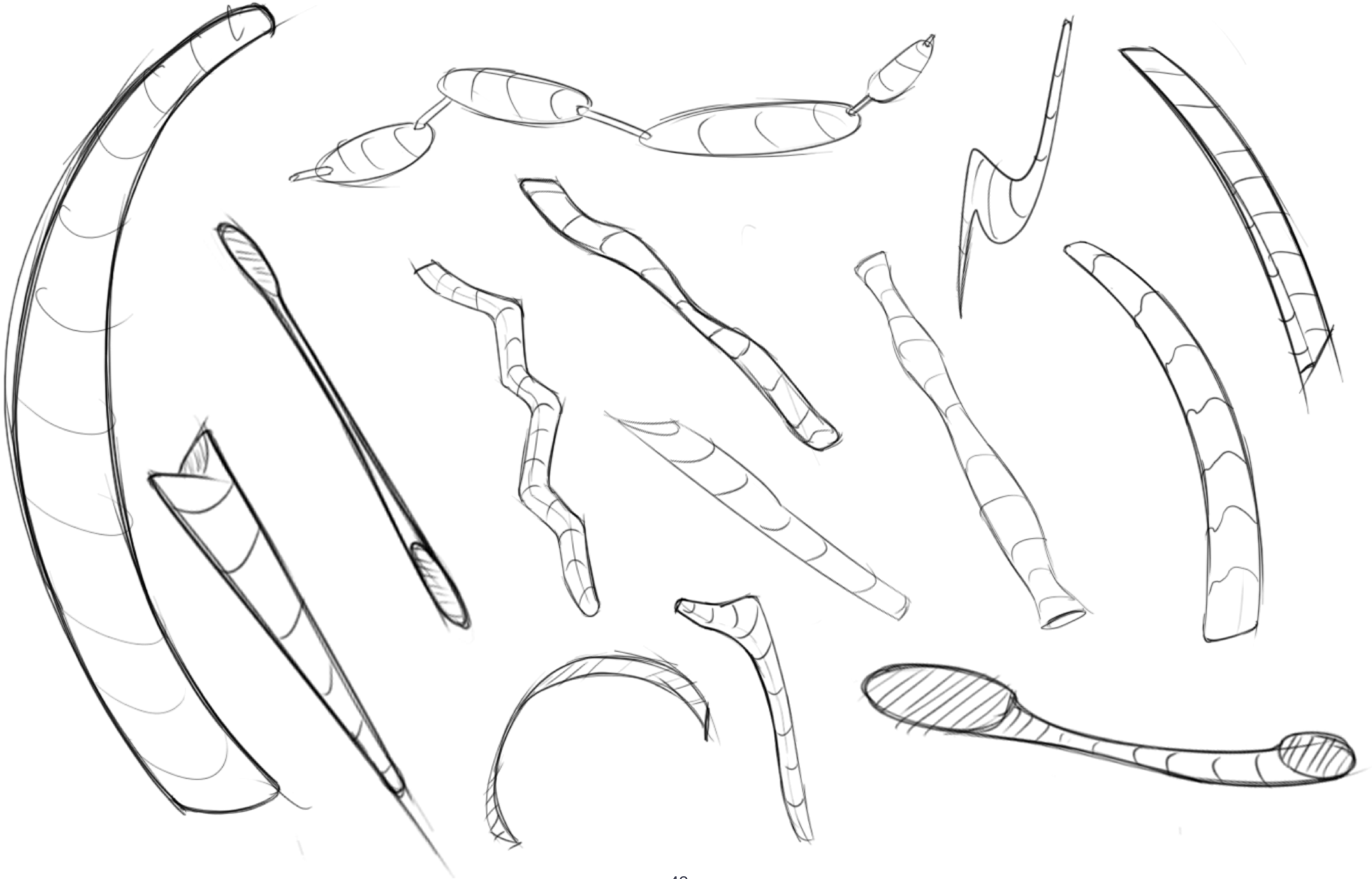

Concept one

Added sails like fabric structure to fill the dead empty space.


Put light source at the top.

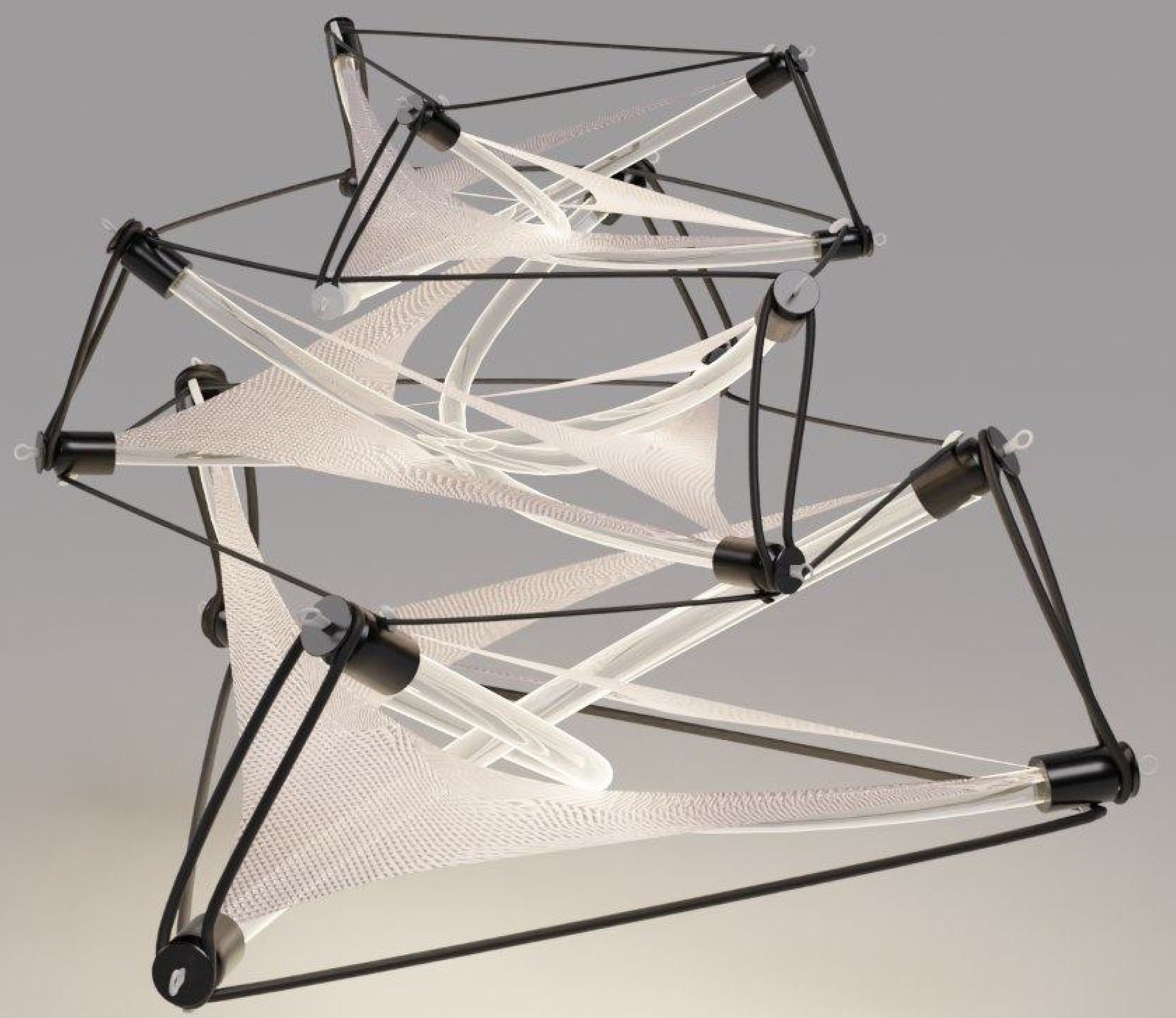
Used stretchable see through fabric so it can change its shape with form.

Stick forms



At this stage, our product comprises only the structural elements, necessitating the addition of aesthetics to attain the appearance of a finalized product. To achieve this, I have opted to engage in ideation focused on the form of the sticks. As these sticks are prominently visible and recurrent in the structure, precision in their use is paramount. Careful consideration is essential during the ideation process to ensure that any alterations contribute positively to the overall aesthetics without creating a cluttered or messy appearance in the structure. The goal is to strike a balance between design enhancements and the clarity of the product's visual presentation.

Final renders



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