

**Architectural Kinetics:
A Study Of Operable Mechanisms for Different Types of Envelopes**

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Abstract

Accepting that one of the main duties of an architect is mastering the tectonic expression of the building and its architectural effect, could there be a mechanism that allows a building or object to change its expression? Could the envelope of a building respond to its exterior context or internal function by changing its appearance? How can the elements of a building screen - whether in wall or roof - change their orientation and configuration to express a response to environments inside or outside?

We know that the modern ideas of “wall-free structure” and “transparency” have begun to change the concept of building envelopes. These changes have allowed envelopes to become lighter, less opaque, and more flexible; and as a result the architect has more freedom in exterior expression. In the Seagram Tower, for instance, while I-beams emphasize the vertical effect of the tower, the glass envelope allows the building to change its surface effect from day to night.

Having more freedom in the exterior expression of buildings has not only brought transparency but also opened a door for a greater interaction between inside and outside. If, in the past, the exterior walls of a building, limited by structural needs, had to carry its weight, today, analogous with living nature, the use of a structural skeleton gives much more freedom of expression and interaction to the exterior envelope of the buildings. Rooted in the ground and running through the building’s mass, instead of outside it, the skeleton takes on the load of the building, and masonry walls can be replaced with partitioning envelopes that are open to freer interpretation.

Influenced by engineers and architects like Chuck Hoberman and Santiago Calatrava, my areas of study since 1997 have been focused on the subject of movement in structures and kinetic architectural elements. I have approached this subject from two points of view. While my first study models explored the ways structures can be folded and transformed, this book is about the investigation and study of envelopes and tectonic planes that can be manipulated through operable mechanisms to change their interior or exterior expression. This study is based on the separation between the mechanisms which are the cause of the movements in the models and the kinetic planes in envelopes that have the duty of interaction between inside and outside. If folding of structures in the early stages of my studies resulted in “metamorphosis”, my current work is about studying mechanisms that change the surface of an envelope and result in “transmutation”.

This is dedicated to my mother and father for their endless love
and also to my dear wife who supported me each step of the way.

Acknowledgment

I would like to express my gratitude to each one of my advisory committee members, Prof. William Galloway, Prof. Scott Gartner, Prof. Robert Dunay and also Prof. Steve Thompson in particular for his support in the school. Moreover I want to thank Prof. David Chip Clark and specialy Prof. Alan P. Druschitz for their help and supervising in the Kroehling foundry.

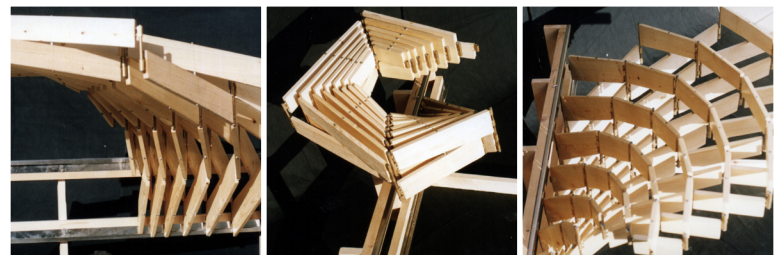
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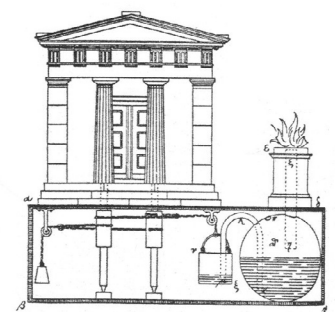
Introduction

The concept of using operable and mechanical elements in architecture goes back to the Hellenistic period, between the 3rd and 1st century BC, when buildings with moving parts were designed by Ktesibios of Alexandria, Philo of Byzantium and Hero of Alexandria. (Alexander Tzonis, Liane Lefaivre, *Structure, Movement and Work of Santiago Calatrava*, page 16). In Vitruvius' "De Architectura", "Mechanics", the designing of machines endowed with kinesis (movement) is included - along with 'Building' and 'Clockmaking' - as one of the three areas which make up the knowledge and activities of an architect" (ibid., page 16). Moving structures appear also in a literary genre referred to as the "Mirabilia", dating from the tenth to fourteenth centuries in Europe and it depicts "foreign buildings in strange and faraway places" that "shower visitors with gifts, or greet them with a hail of arrows" (ibid., page 18).

In the sixteenth and seventeenth centuries, we see a plethora of "astounding mobile structures, machines, instruments of spectacle and pleasure", that are "devoid of any productive objective - but also stripped of deeper magical or religious connotation". During this period, kinetic mechanisms "play a major role in both garden and urban settings, and are perhaps more significant than static structures, building or sculptures" (ibid., page 19). With the arrival of the twentieth century, operable machines and kinetic parts play a huge role in both the construction process and maintenance of buildings. However, although they contribute much to functional goals in buildings, they rarely assist them in their architectural expressions and effects.



1. A study of shading canopy, 1999
The study is based on spirally folding of a structural cantilever.



2. Hero of Alexandria's pneumatic temple door opener. From Friedrich Klemm. *A History of Modern Technology*. Cambridge. MIT Press. 1964 (Alexander Tzonis, Liane Lefaivre, *Structure, Movement and Work of Santiago Calatrava*, page 17)

There are two major points that have influenced this study:

State of stability

Accepting gravity as the major force a building or any object will encounter, one of their first duties is carrying their load to the ground, and reaching the state of stability. The problems of overcoming gravity is not exclusive to buildings and static objects; even objects in motion need to keep their stability, to prevent collapse and disintegration. However, the existence of gravity on Earth seems to have had a deeper influence on design than just a reactive shaping of the form based on stability. To explain further, I refer to the history of sculpture and figurative art in Greece.

According to Alexander Tzonis' book "Movement, Structure, and the Work of Santiago Calatrava", "the idea of 'progress' in the art of Ancient Greece has been equated with the gradual disengagement of the limbs away from the simple pillar-like 'block' structure of the human body, in other words the realistic representation of movement arises through a corresponding modular decomposition of structure" (ibid. page 138). He also mentions that "divinities and athletes assume the most articulated and complex positions, where all members of the body appear as if torn from the torso, to become engaged in the most 'lively', 'elaborate' and even 'violent' acts". The sculptor "Policlitos" in his book "The Canon", systematically codifies "the disengagement of actual members of the human body from the primitive block and the resulting arrangement of compositional components in order to achieve a sense of movement" (ibid. page 138).

With desire to "representation of the movement, including the violent movement" and "exaggerated body position" between artists the framework of Policlitos in his book "The Canon" remains the basic reference. However, during the Renaissance, a new concept namely "Contraposto" (counter position) – which is translation into Italian of the Greek word "antithesis" - appears between theoreticians of design (ibid. page 143). The interesting point about this new concept is how these theoreticians combined "the visual mode and the tradition of associating configuration with movement, according to 'The Canon' and the verbal mode and the tradition of associating a literary figure with a meaning, stemming from poetic" (ibid. 143).

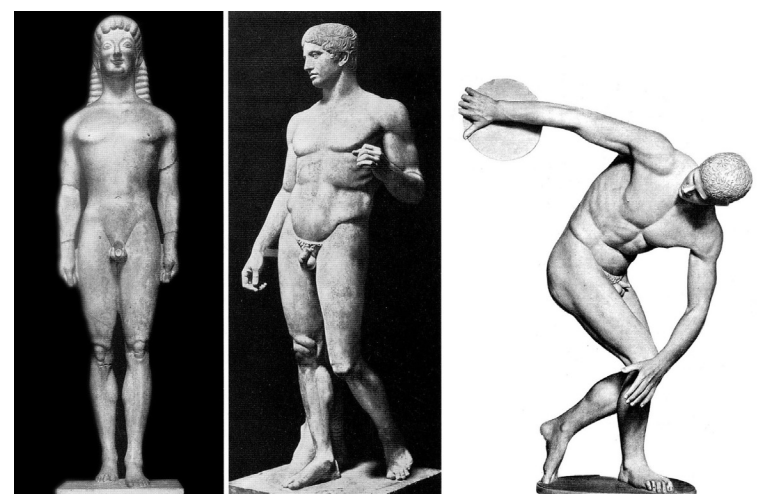
In 1584 Giovanni Paolo Lomazzo explains how 'the flame of fire', which he describes as the resemblance of the letter "S", is the best form to represent motion. He also refers to Michelangelo as the artist who "applied 'serpent-like figure' (as he calls this S-form) to the human body in particular in order to empower it with the movement" (ibid. 143). Lomazzo goes on to explain "how the body can be arranged in a manner which, while destroying its symmetry but preserves its balance", and "the S-form is a very abstract, extreme schematization of the contraposto of the Canon" (ibid. 143-144).



From left to right:

3. Alexander Calder, Mobile, 1967 (Calder: an autobiography with picture, page 193)

4. Edgar Dugas, Two Dancer on the Stage (Richard Kendall, Jill Devonyar, "Degas and the Ballet, Picturing Movement", page 49)



From left to right:

5. Kouros from Tega, first part of the 4th century BC. Munich

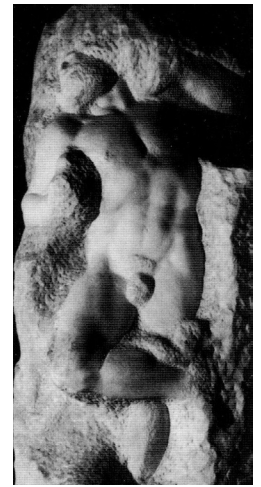
6. The Diadoumenos of Policlitos, second half of the 5th century BC. Copy Athens, National Museum

7. Myron's Discobolos, mid-4th century BC. Copy. Rome

(Alexander Tzonis, Liane Lefaivre, Structure, Movement and Work of Santiago Calatrava, page 139)

Therefore, as Tzonis says, “although these investigations into contraposto and the serpentine figure represent the moving body, they are nevertheless abstract concepts, applicable to any object” and “they capture the moment when a structure, as if arrested by an invisible power, is poised in a state of equilibrium and immobility, on the brink of possible collapse” (ibid. 144). What is interesting is how the aesthetic frameworks in figurative art are defined in accordance with the scientific laws of physics and stability to capture and express motions in figures.

8. Michelangelo. Awakening Slave. Galleria dell'Accademia. Florence (Alexander Tzonis, Liane Lefaivre, Structure, Movement and Work of Santiago Calatrava, page 121)



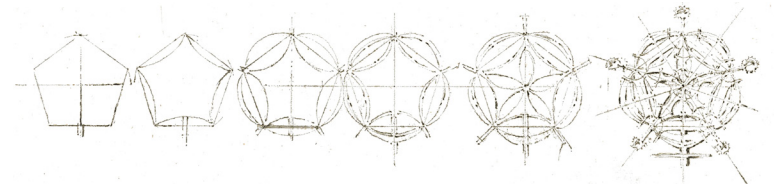
Geometry and Ornament

Geometry has two important roles in this study. The first role of geometry is to design the mechanical movements of operable elements, apart from the forces that cause motion and stability. The goal of this role – namely, “Kinematic” - is to provide the design of desirable and proper motion for envelopes. However, this is not the major purpose of this study.

More importantly, other major role of geometry is in construction and ornamentation. Although architecture and figurative art have common goals in achieving the state of stability and showing expression, grown from the earth to the sky, any architectural structure has a strong bond to its place; this lets architecture set up a new visual grammar for its expression, one only loosely related to figurative art. If figurative art has to borrow or imitate many of its conceptual forms from other existences, architecture has the capability to create its own aesthetic grammar and express itself based on the way it is structured, raised and constructed.

In this technique of expression, known as tectonic expression, ornament plays an important role and, as Owen Jones has said, “Construction should be decorated. Decoration should never be purposely constructed” (The grammar of Ornament, London, 1856, page 5). Ornament should be “a part of surface or substance that receives it than if it looks ‘stuck on so to speak’ ” and “it should appear, when completed , as though by the outworking of some beneficent agency it had come forth from the very substance of material and was there by the same right that a flower appears amid the leaves of its parent plant” (Louis H. Sullivan, Kindergarten Chats and other writings New York 1947, page 189). And as Farshid Mousavi says in her book “The Function of Ornament” “It is the figure that emerges from the material substrate, the expression of embedded forces through process of construction, assembly and growth. It is through ornament that material transmits effect. Ornament is therefore necessary and inseparable from the object” (Farshid Mousavi, The Function of Ornament, page 8).

As geometry has an important role in giving order and organizing the process of structuring and construction, it naturally has its own effect on the ornamental elements that appear on building envelopes. While the structure holds and carries different elements of a building or an object, geometry codifies the whole process of design, construction and assembly. After an architectural structure or object is developed, geometry hides itself amidst the object and like an inner framework, its effects are never invisible, but it can always be traced down.



9. The Awakening Of The Pentagon. *"The idea must steadily be held in mind that the rigid geometric form is considered as a container of energy upon which a germinal, liberating will is imposed by man's free choice, intelligence and skill"*. (Louis H. Sullivan, A System of Architectural Ornament, Plate 4)

The organization of this book is as follows: a study of the primary operable mechanisms intended for different types of envelopes, followed by a large-scale study of operable envelope on a dome and concluding with a description of a luminary object that can change its light effect by an operable screen.

References

1. Alexander Tzonis, Liane Lefaivre, "Structure, Movement and Work of Santiago Calatrava"
2. Owen Jones, "The grammar of Ornament", London, 1856
3. Louis H. Sullivan, "Kindergarten Chats and other writings", New York, 1947
4. Farshid Mousavi, "The Function of Ornament"
5. Louis H. Sullivan, "A System of Architectural Ornament"
6. Calder: an autobiography with picture
7. Richard Kendall, Jill Devonyar, "Degas and the Ballet, Picturing Movement"

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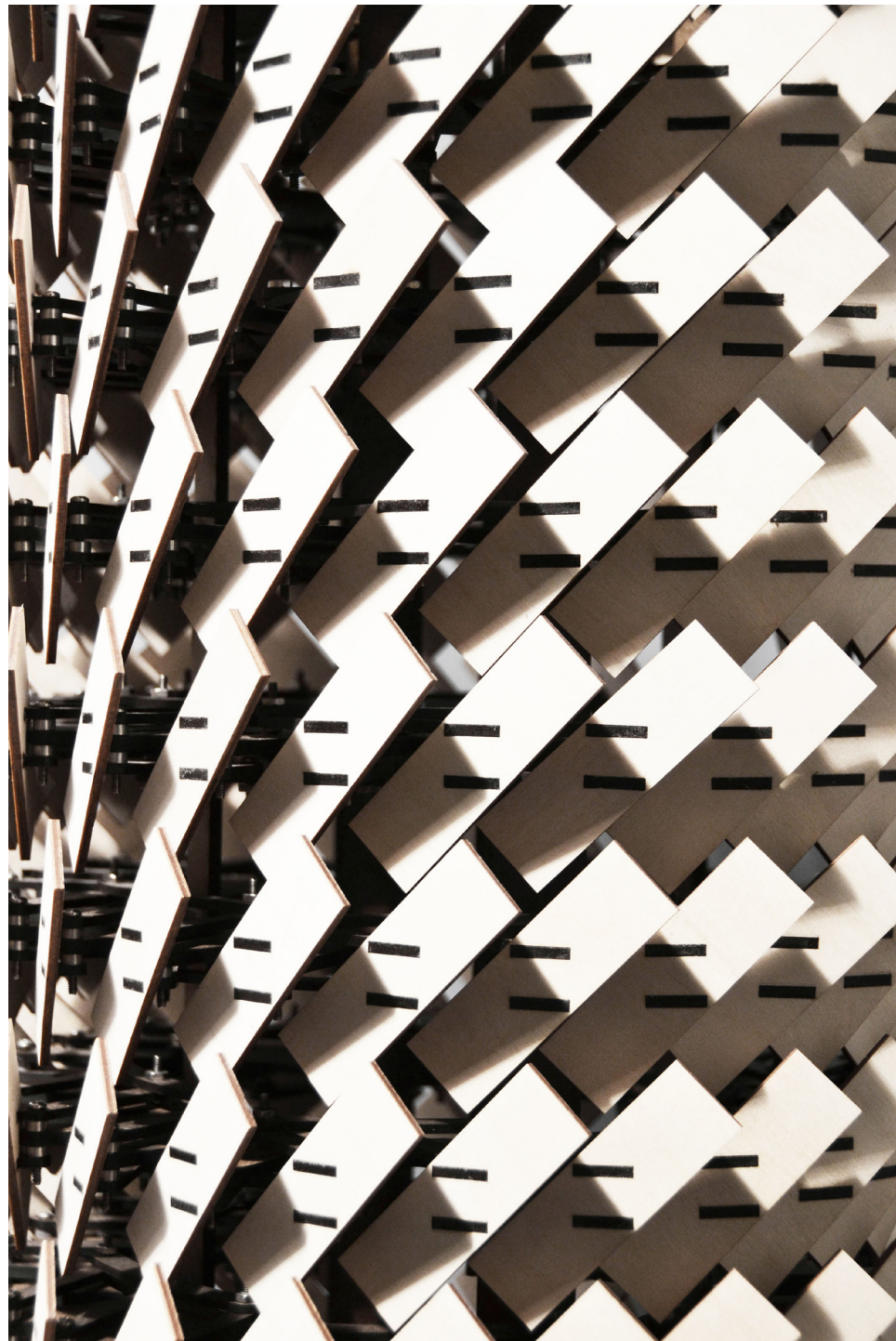
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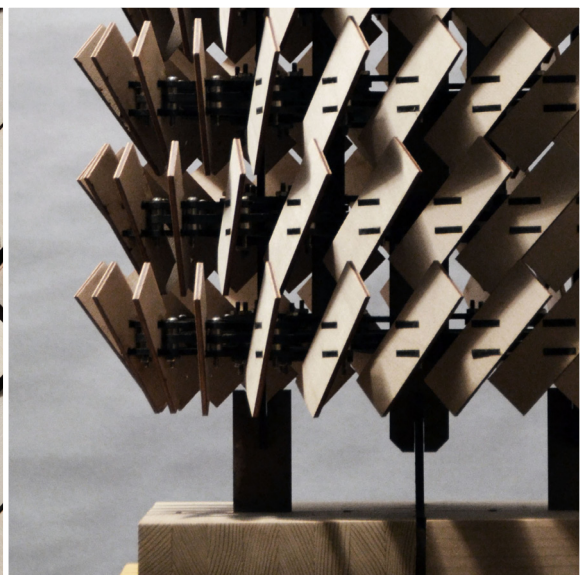
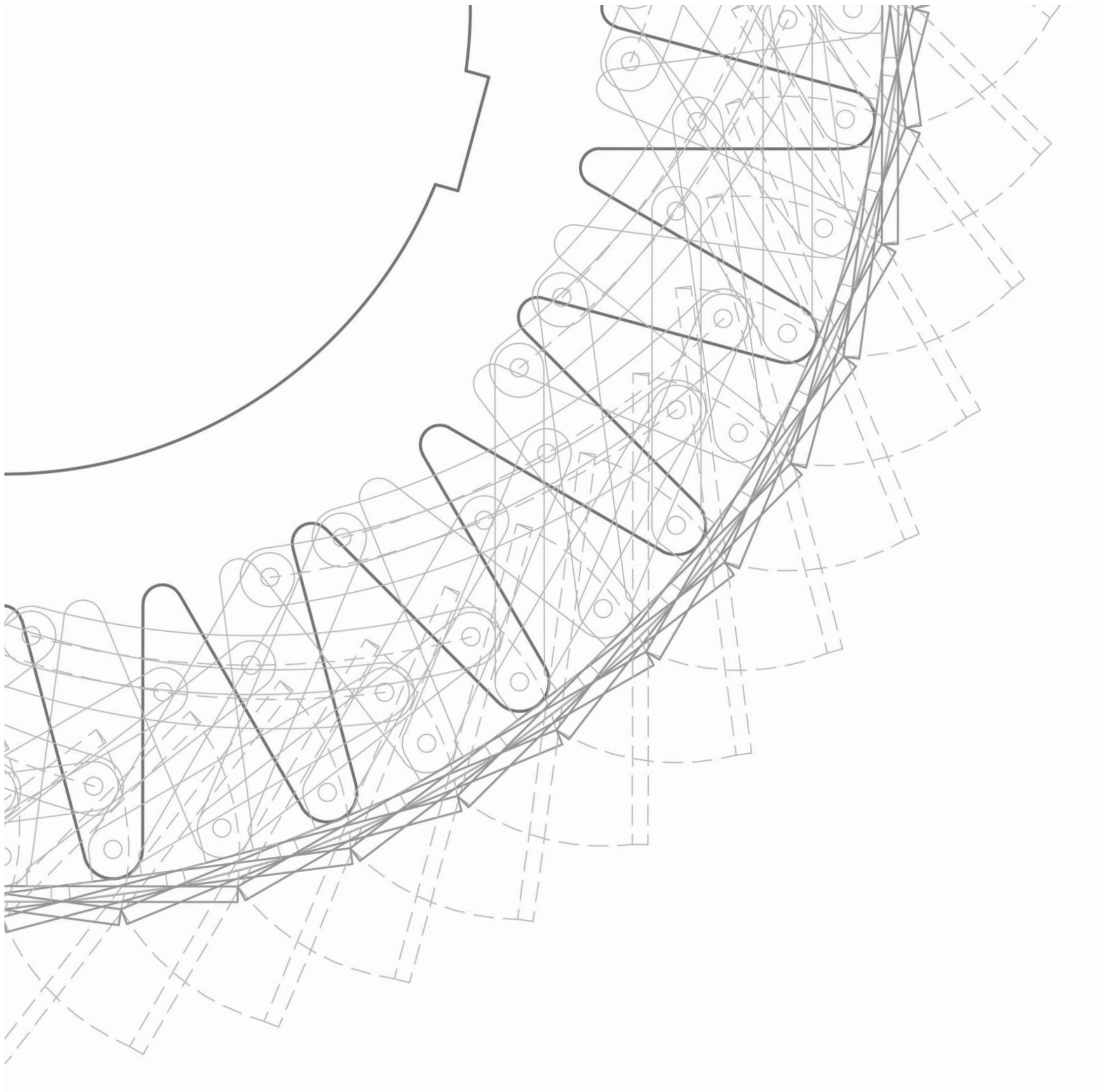
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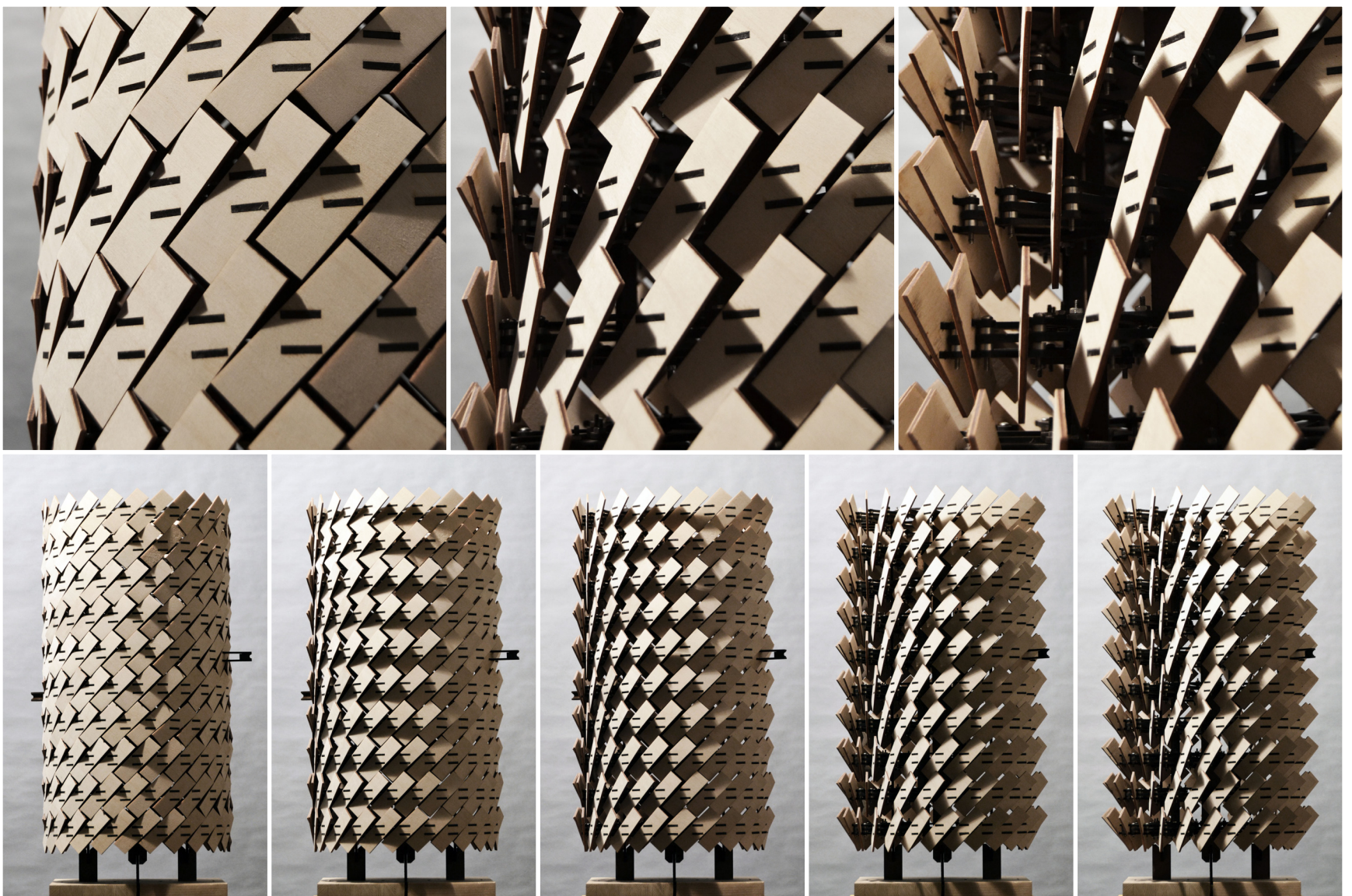
A study of operable mechanisms for different types of envelopes

This chapter will present the primary study models that explore operable mechanisms for different types of envelopes. While the exterior envelopes are color-coded with the white material the dark elements have structural and mechanical roles and hold and move the envelopes.

Study Model-1

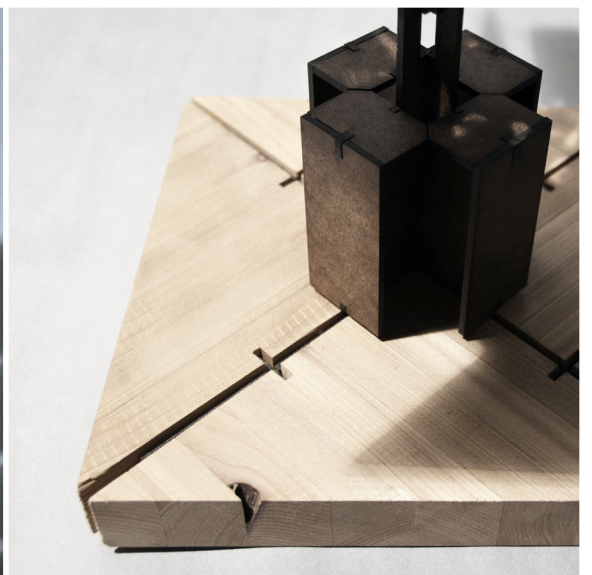
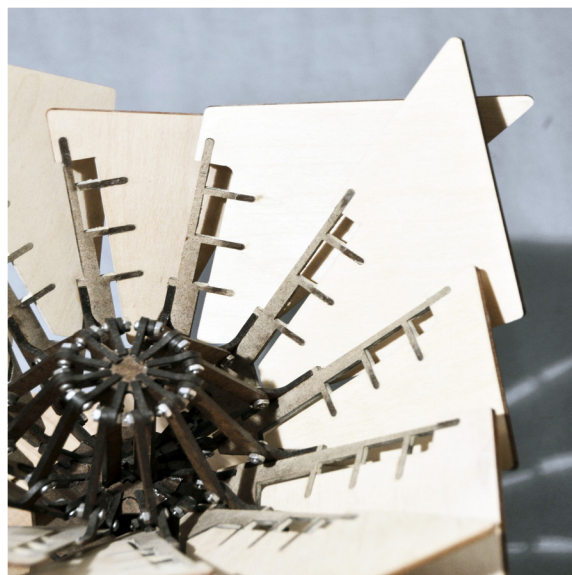
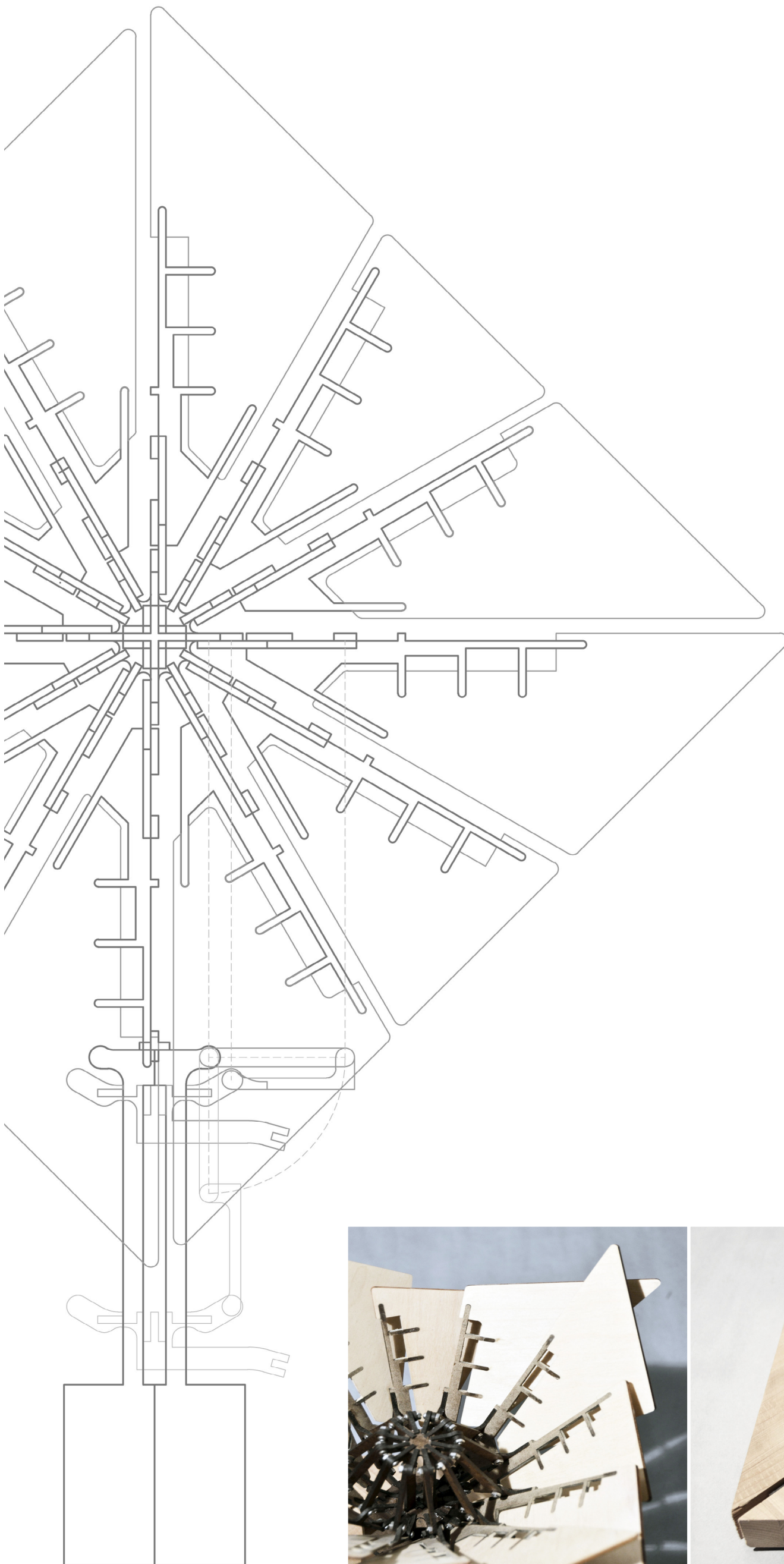






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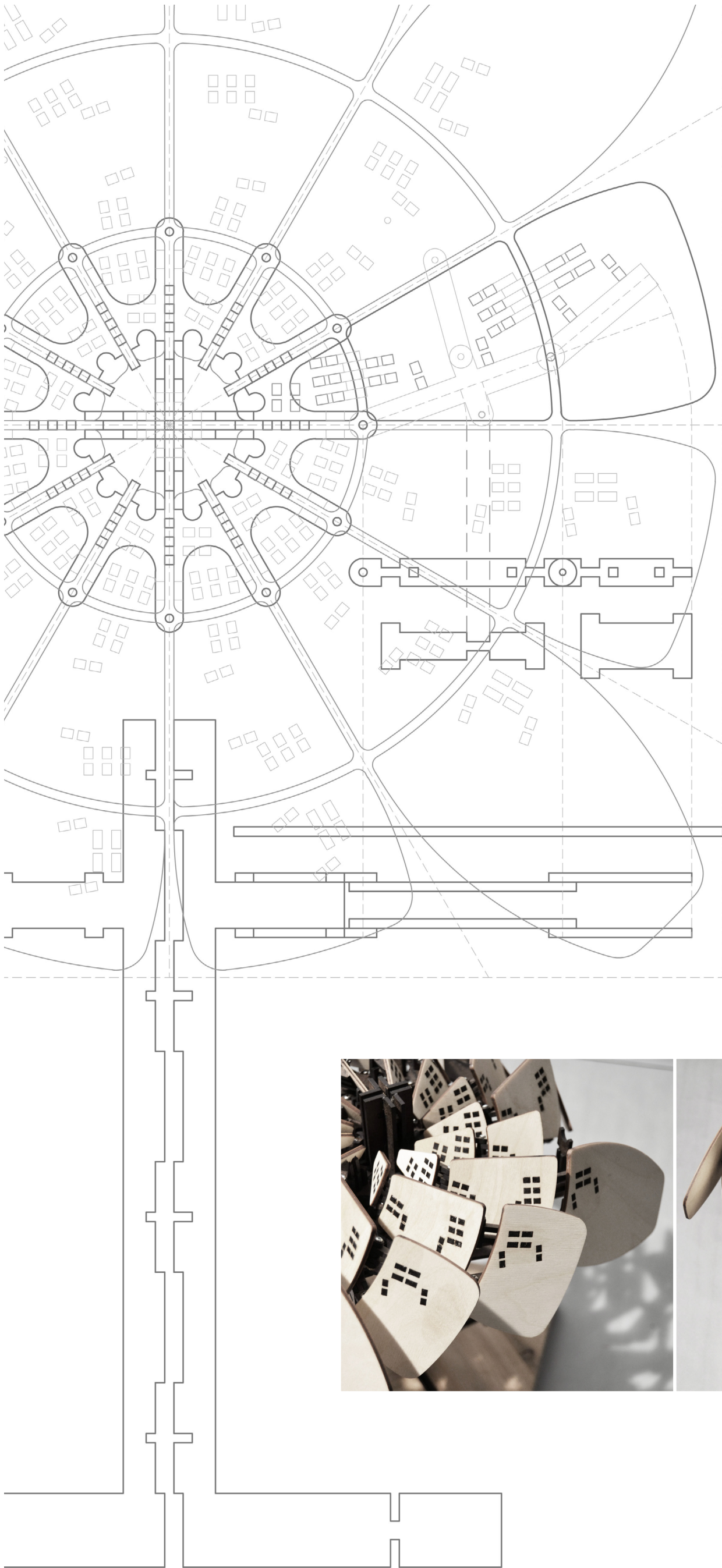


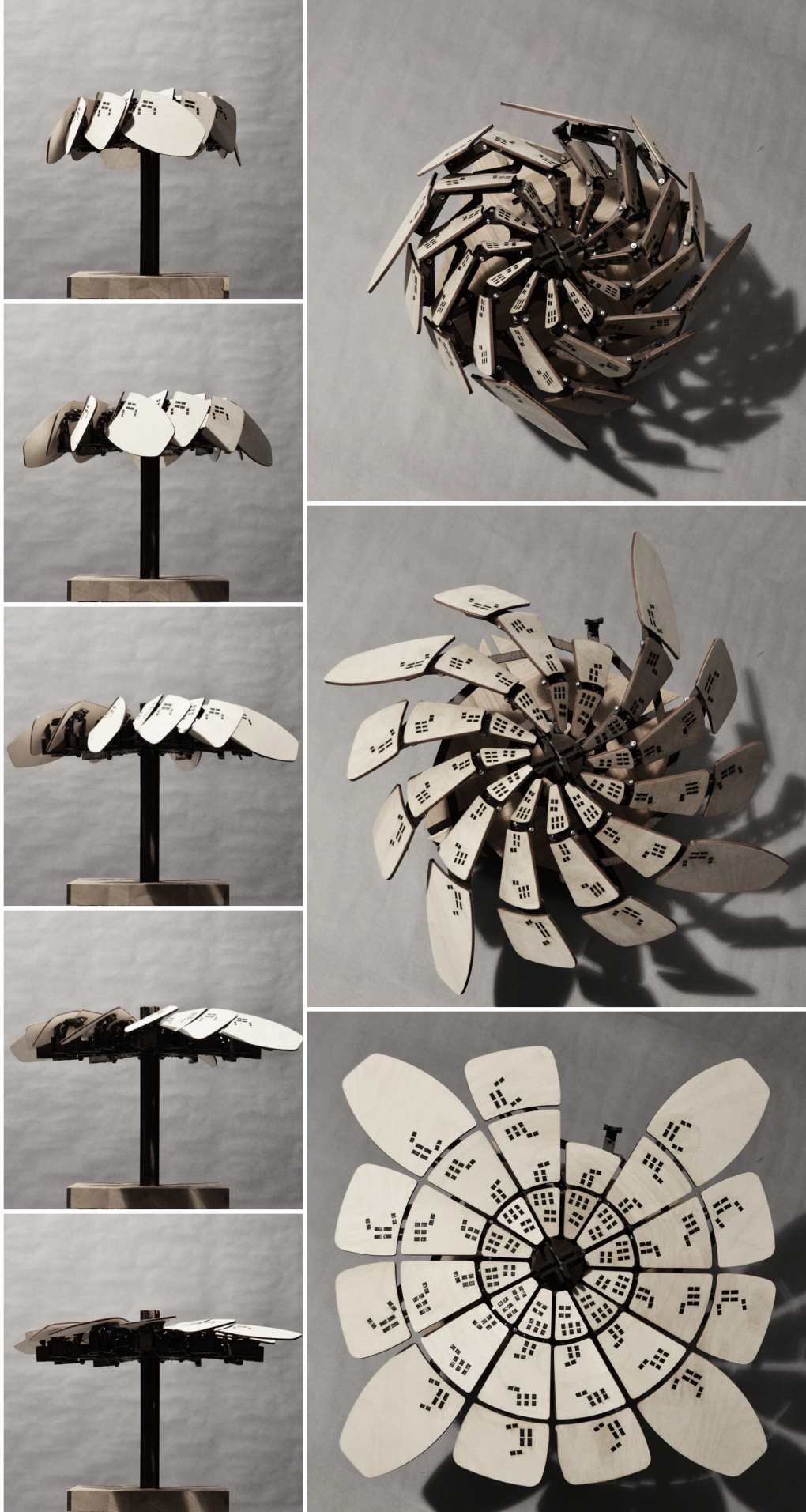




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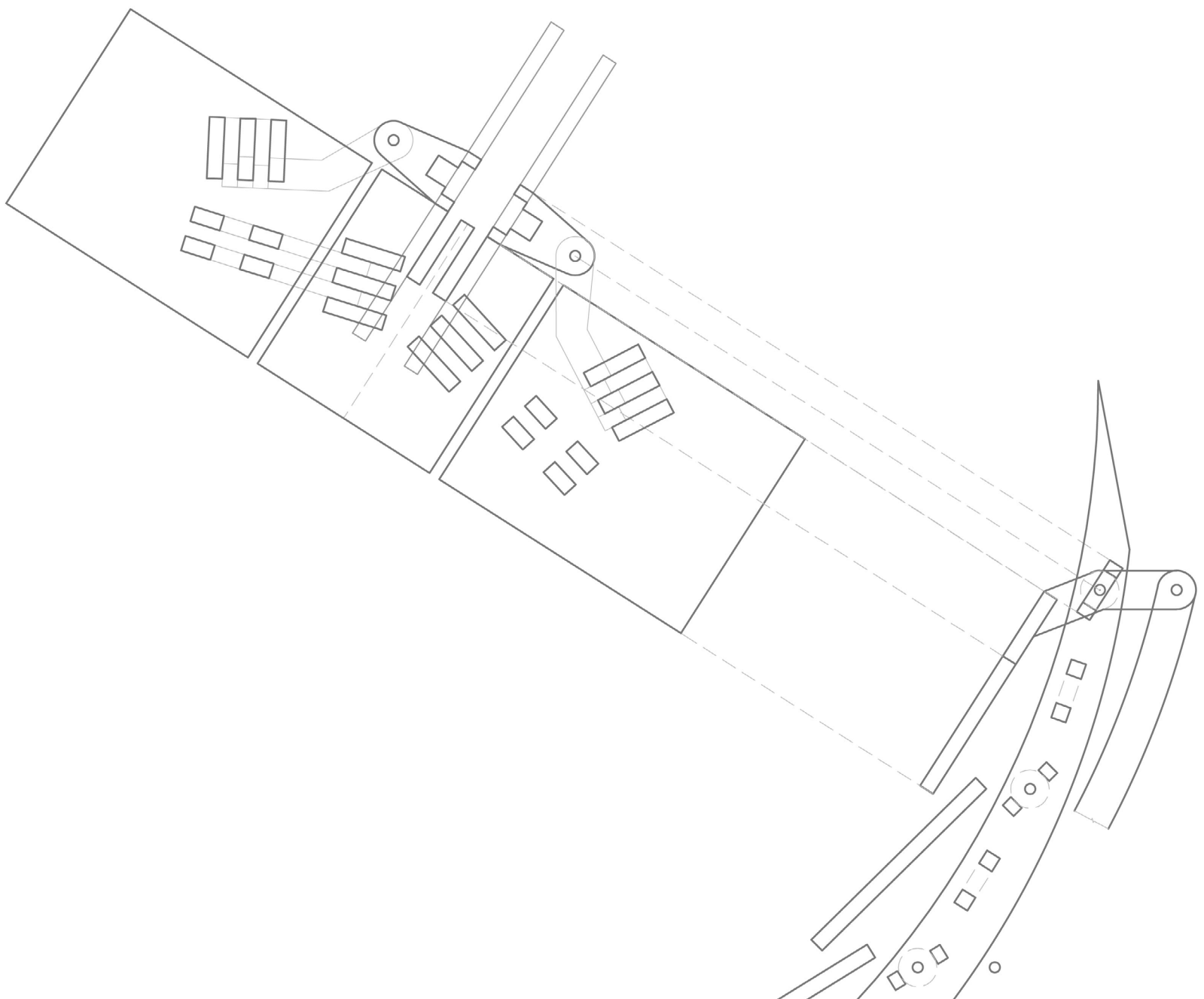
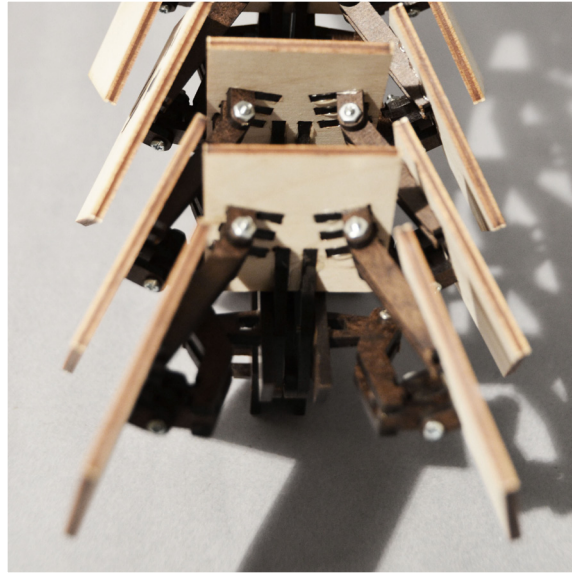


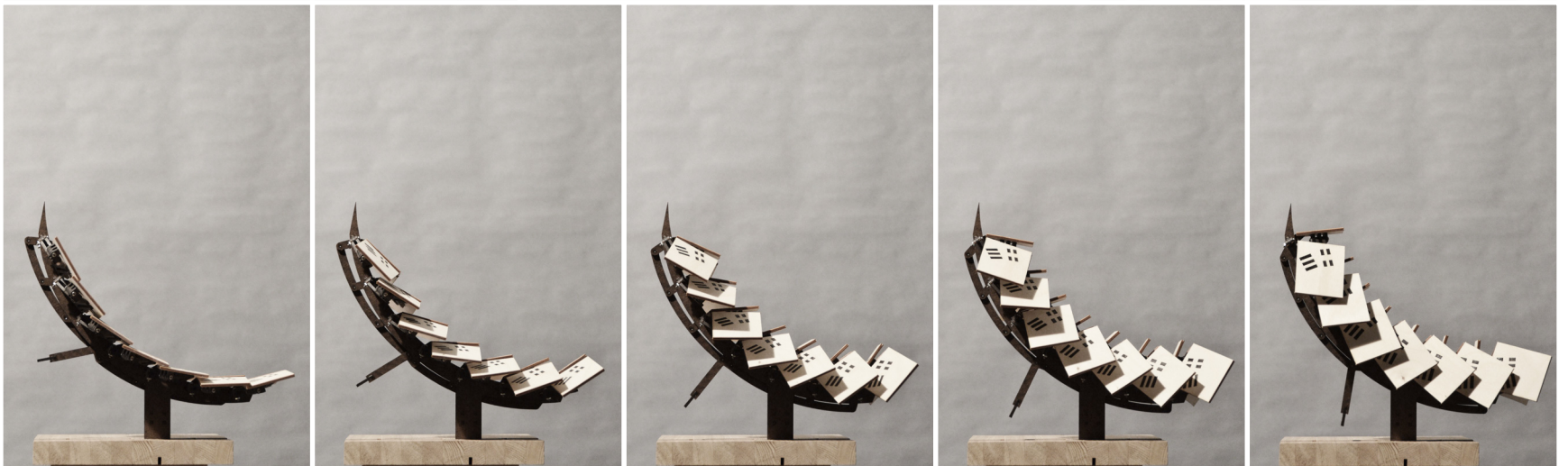
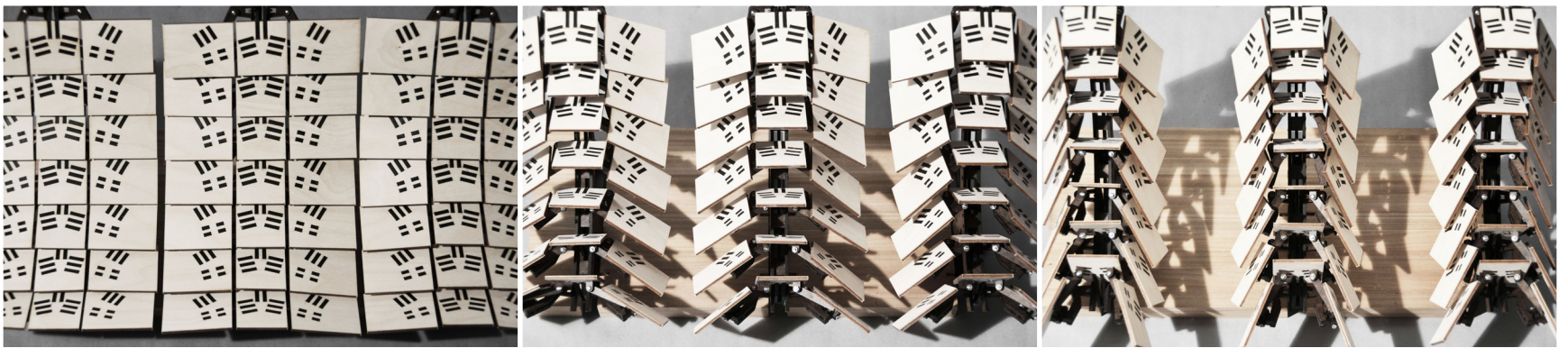




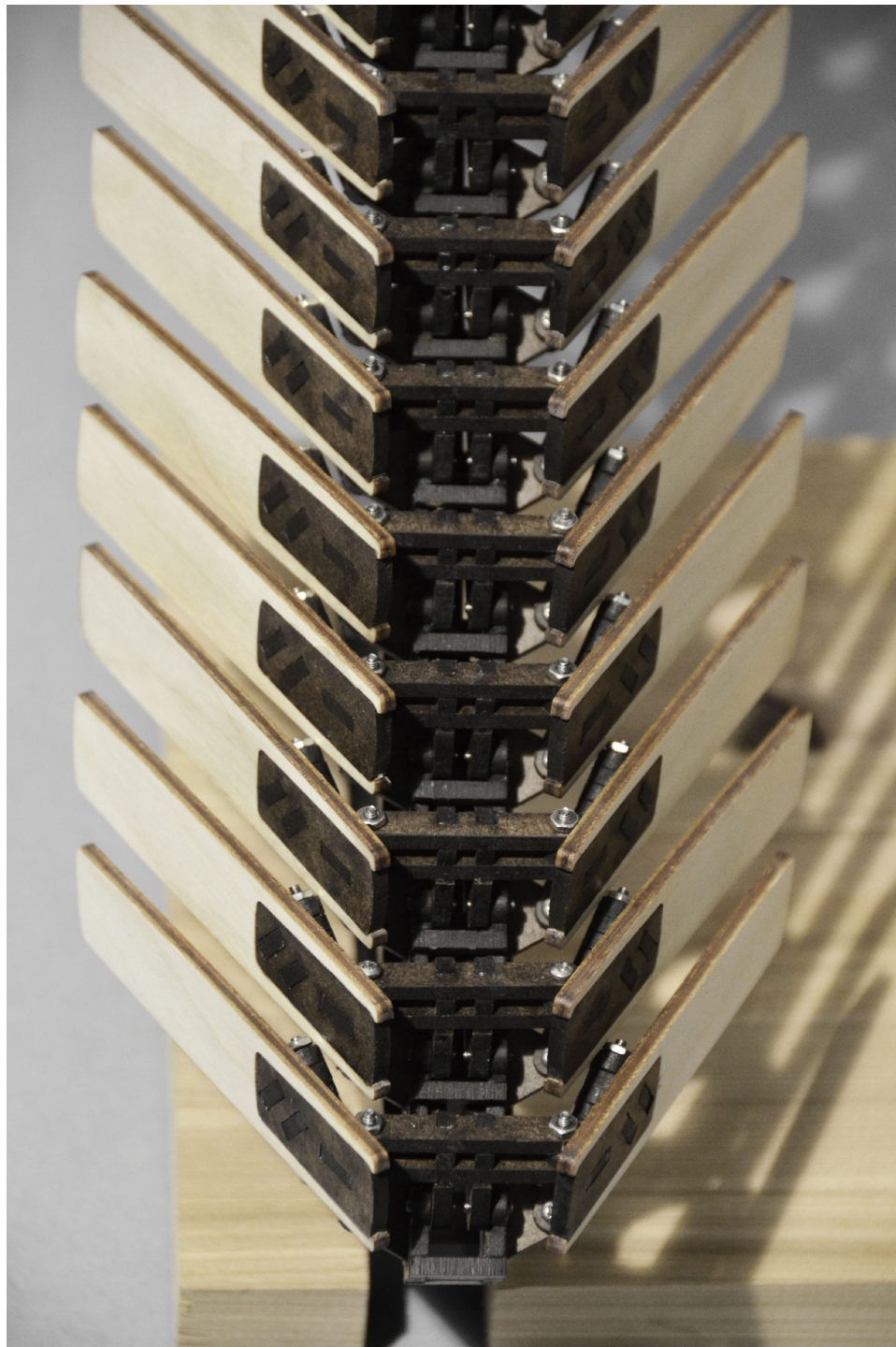
Study Model-4

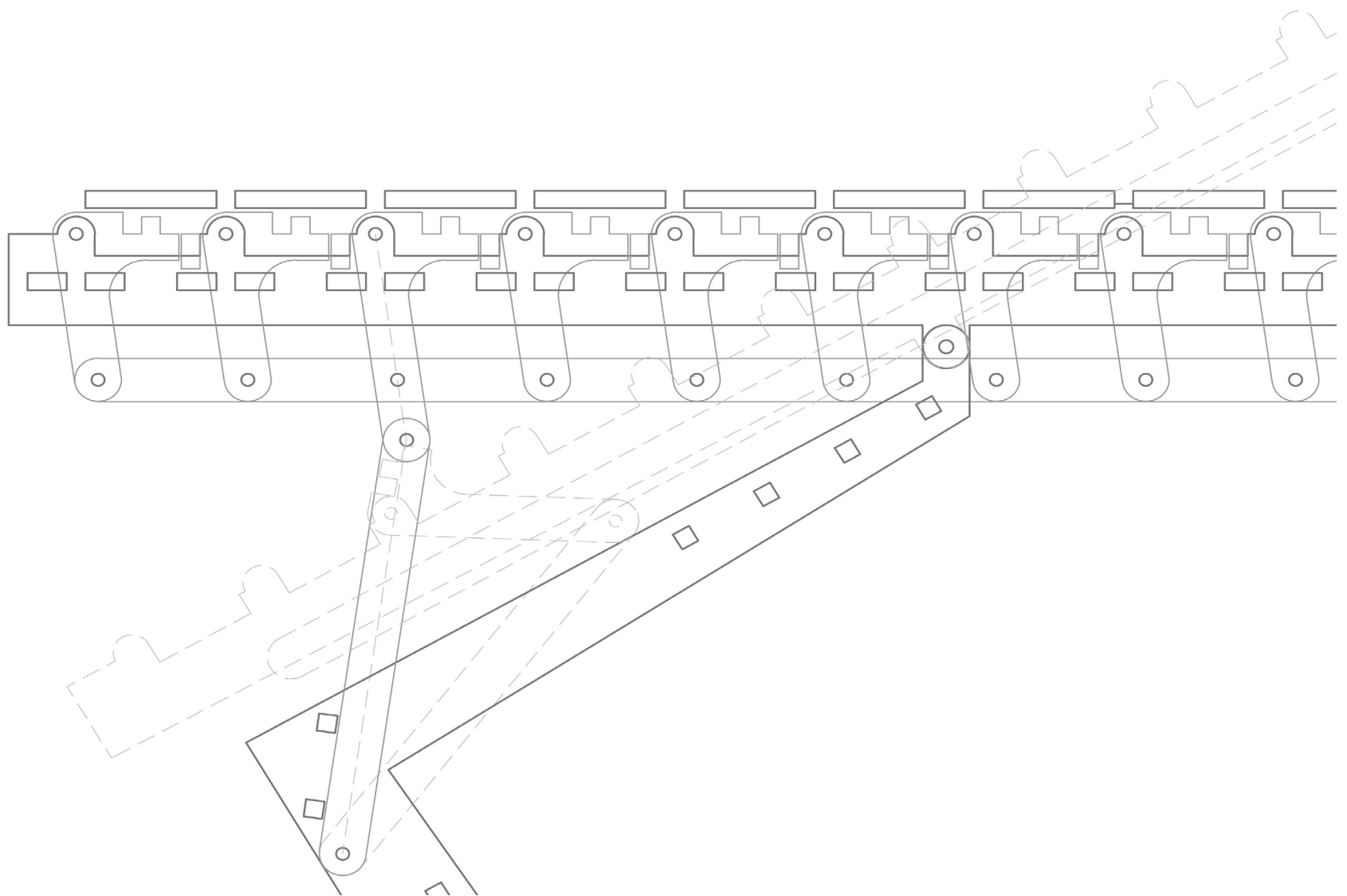
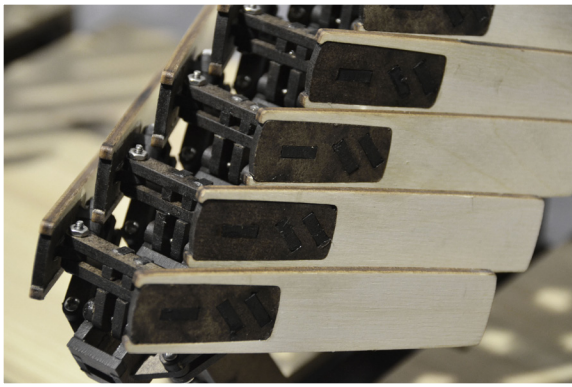
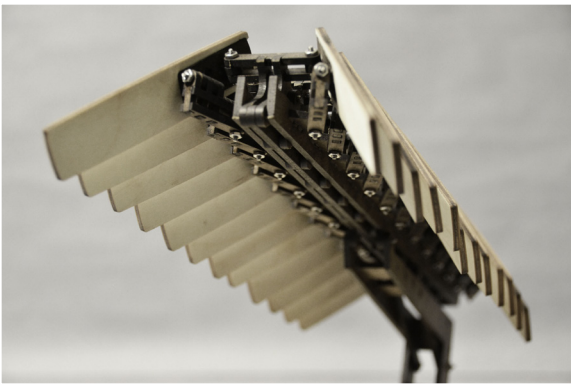
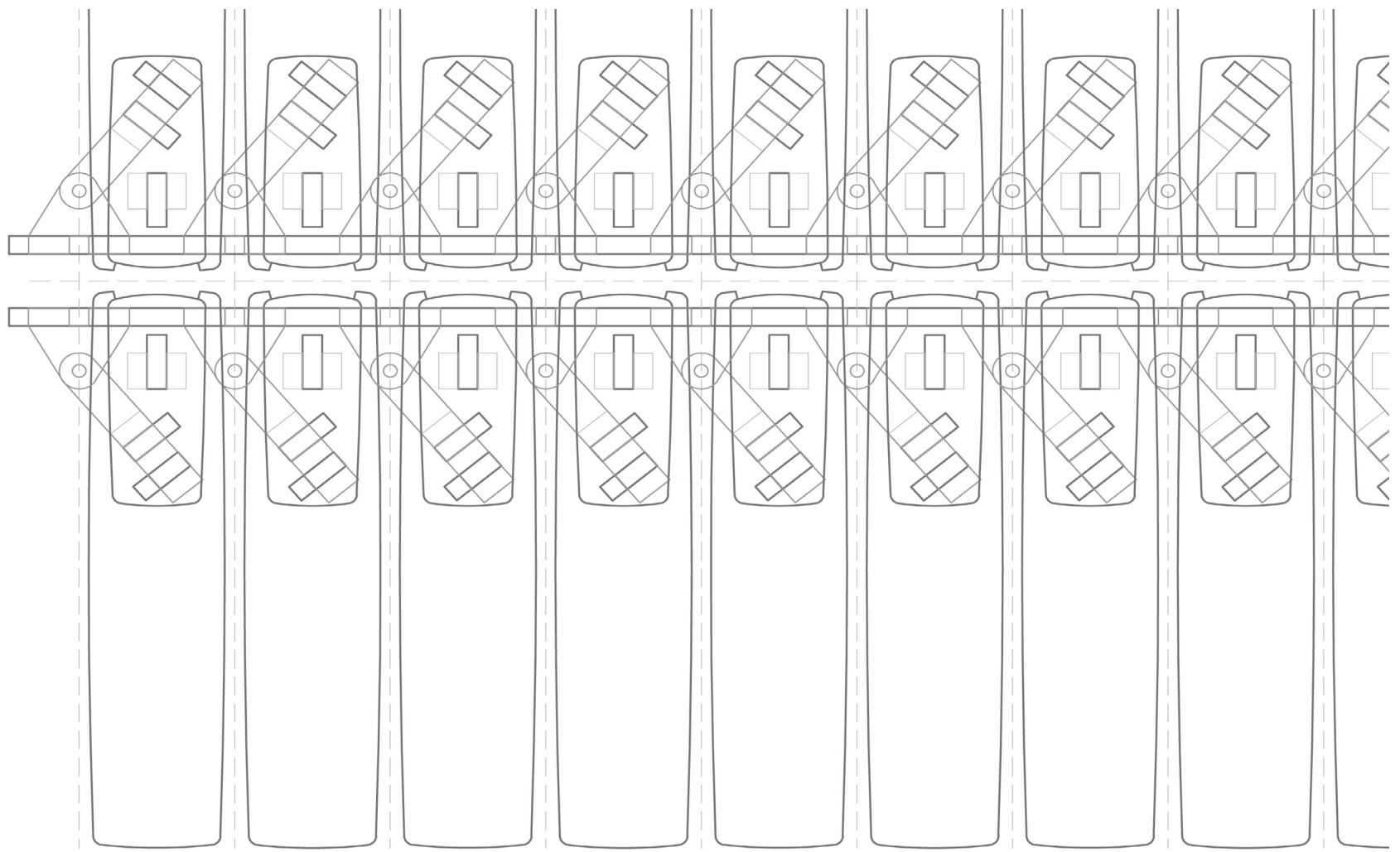


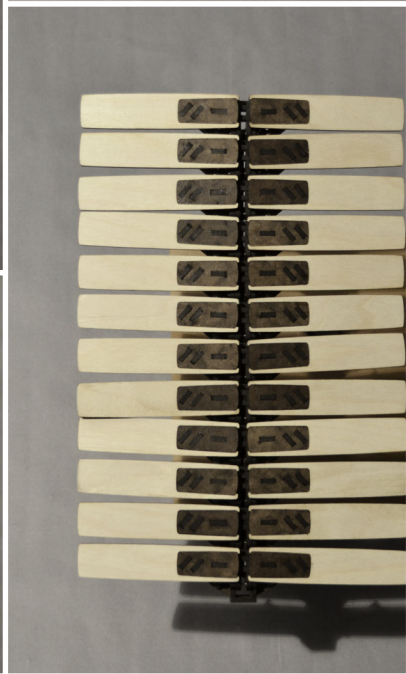
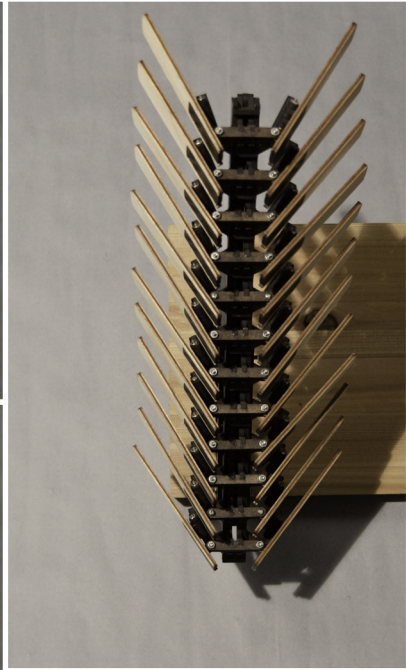
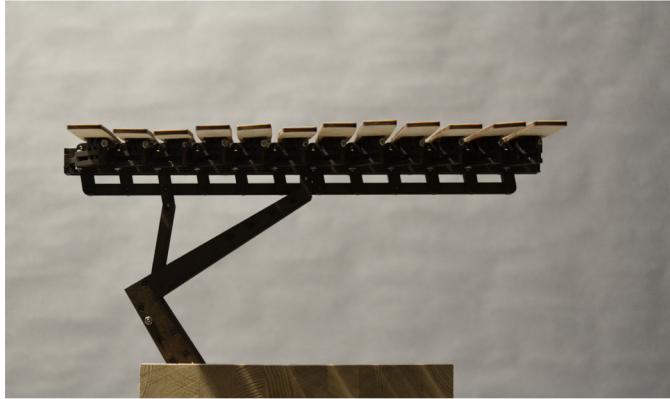
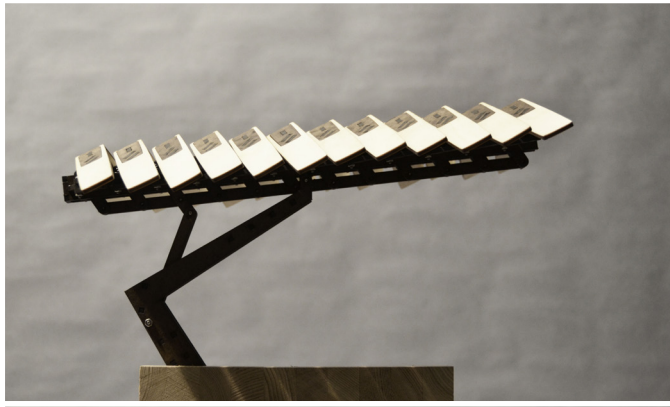
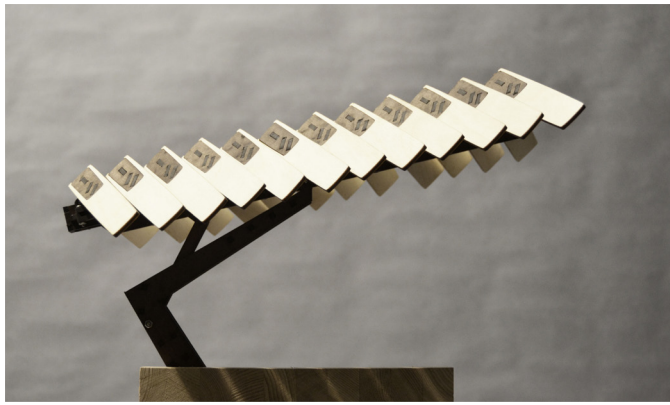
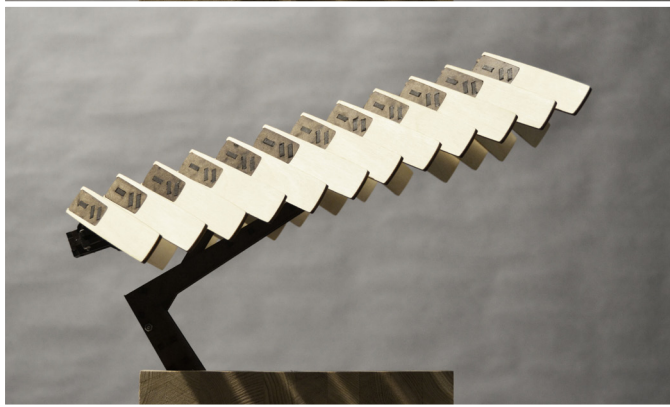
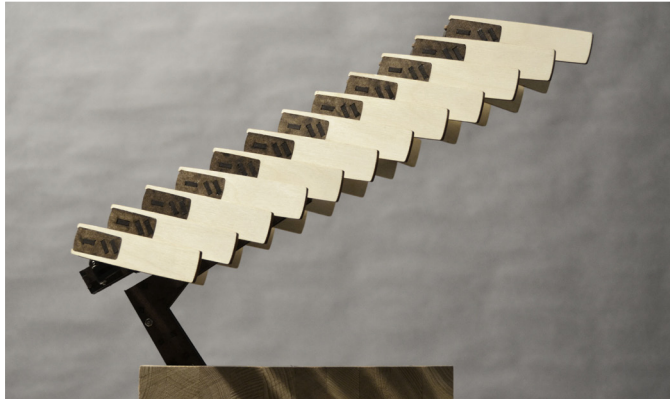




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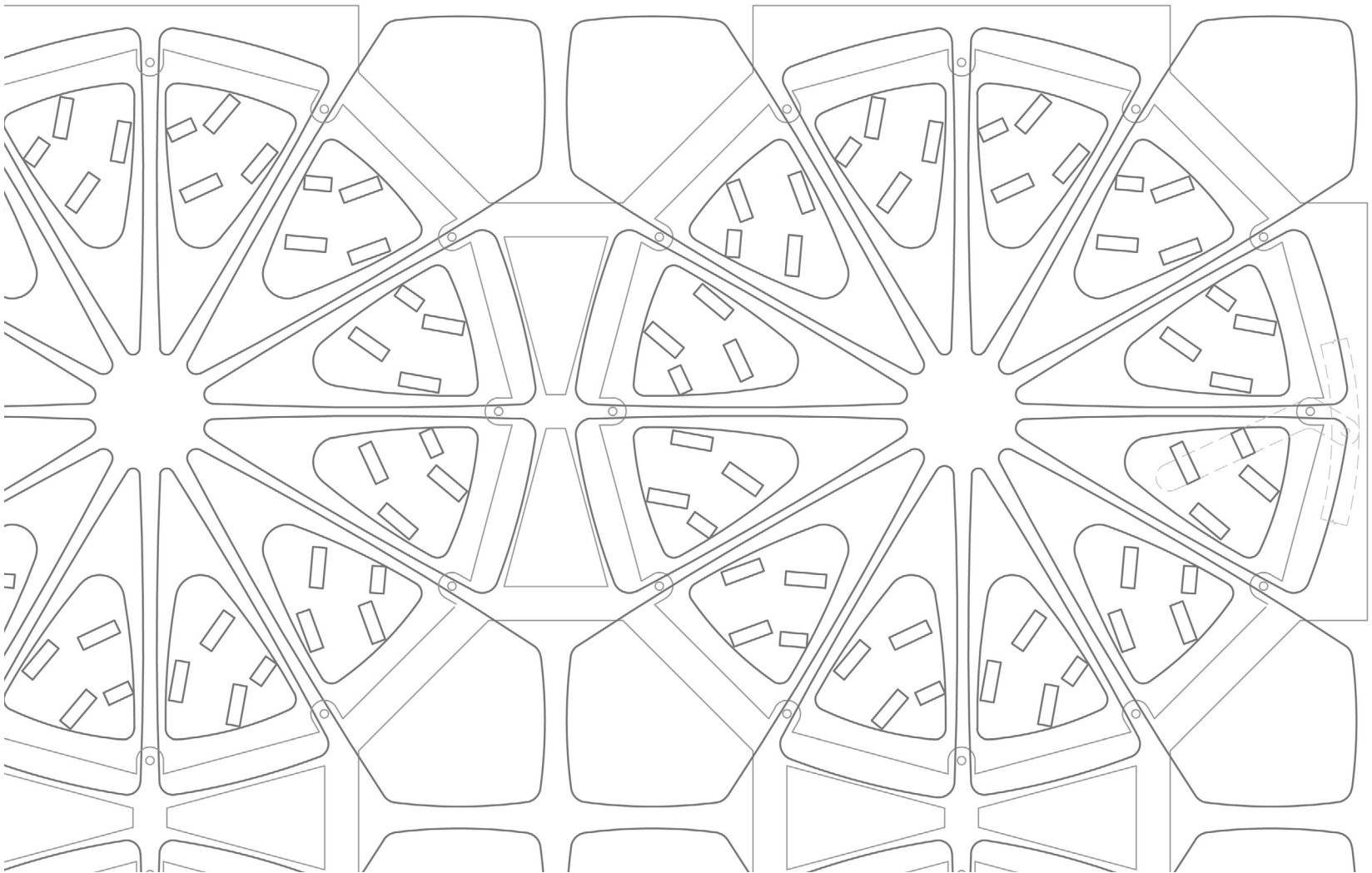


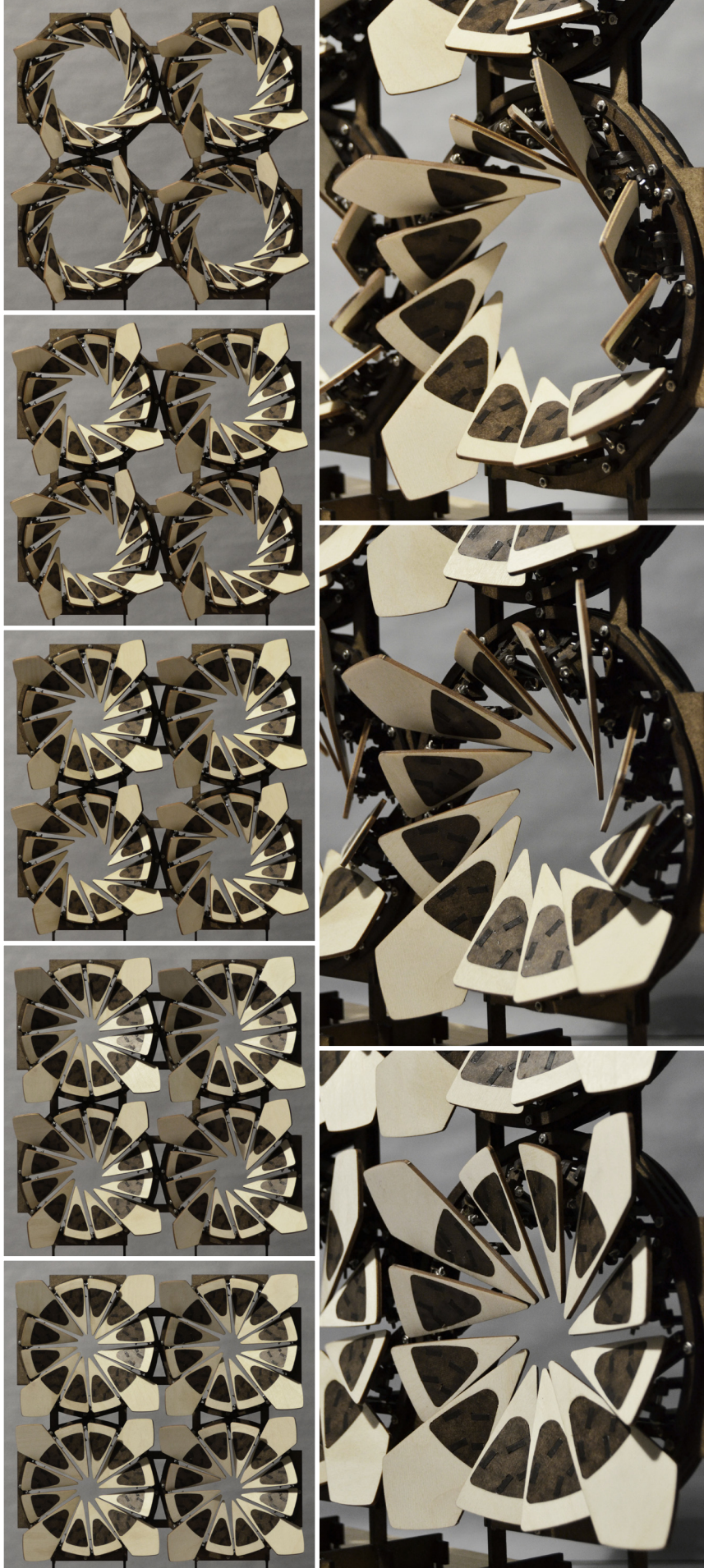




Study Model-6



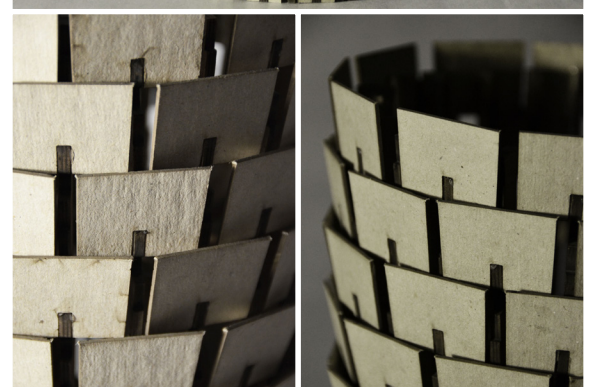
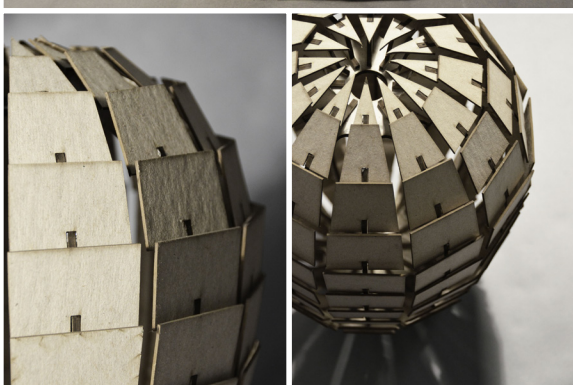
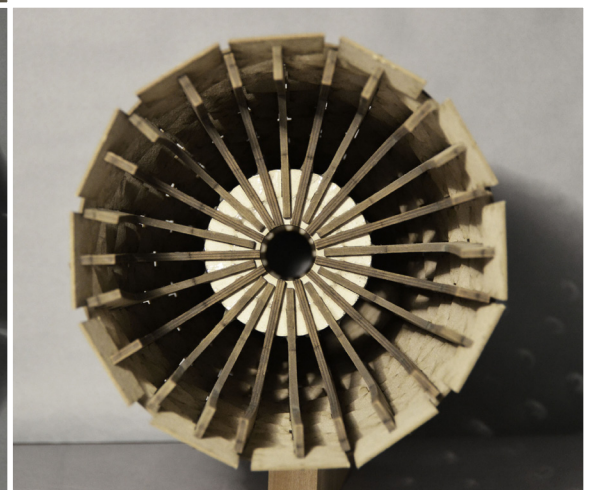
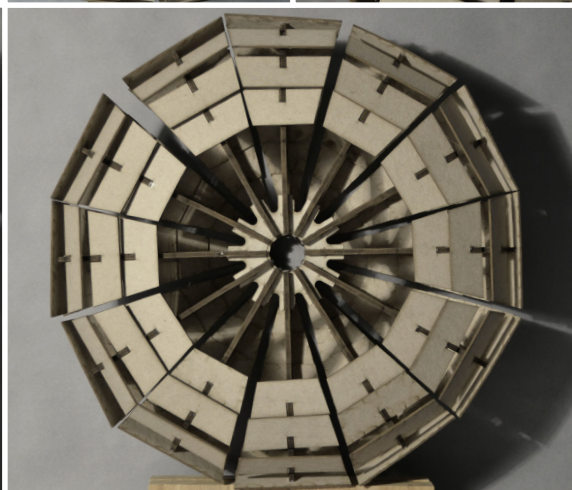
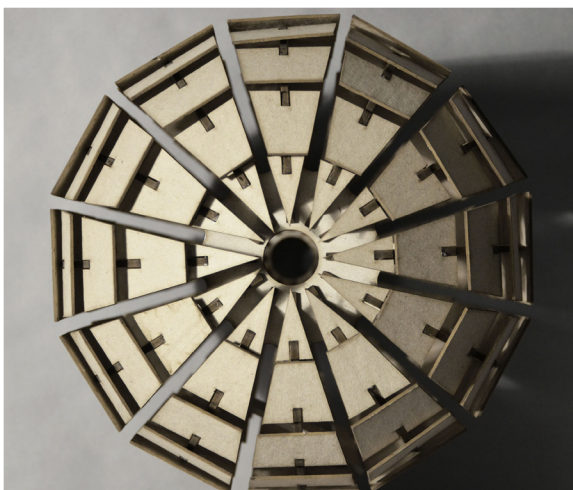
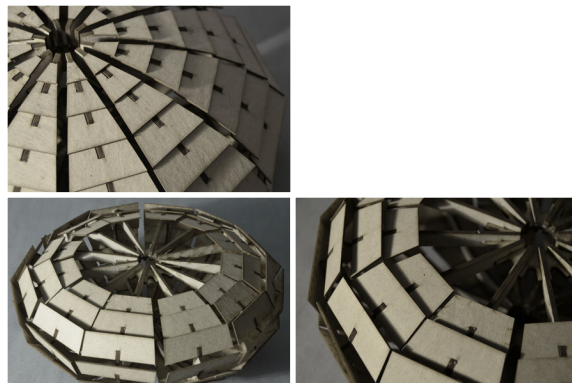




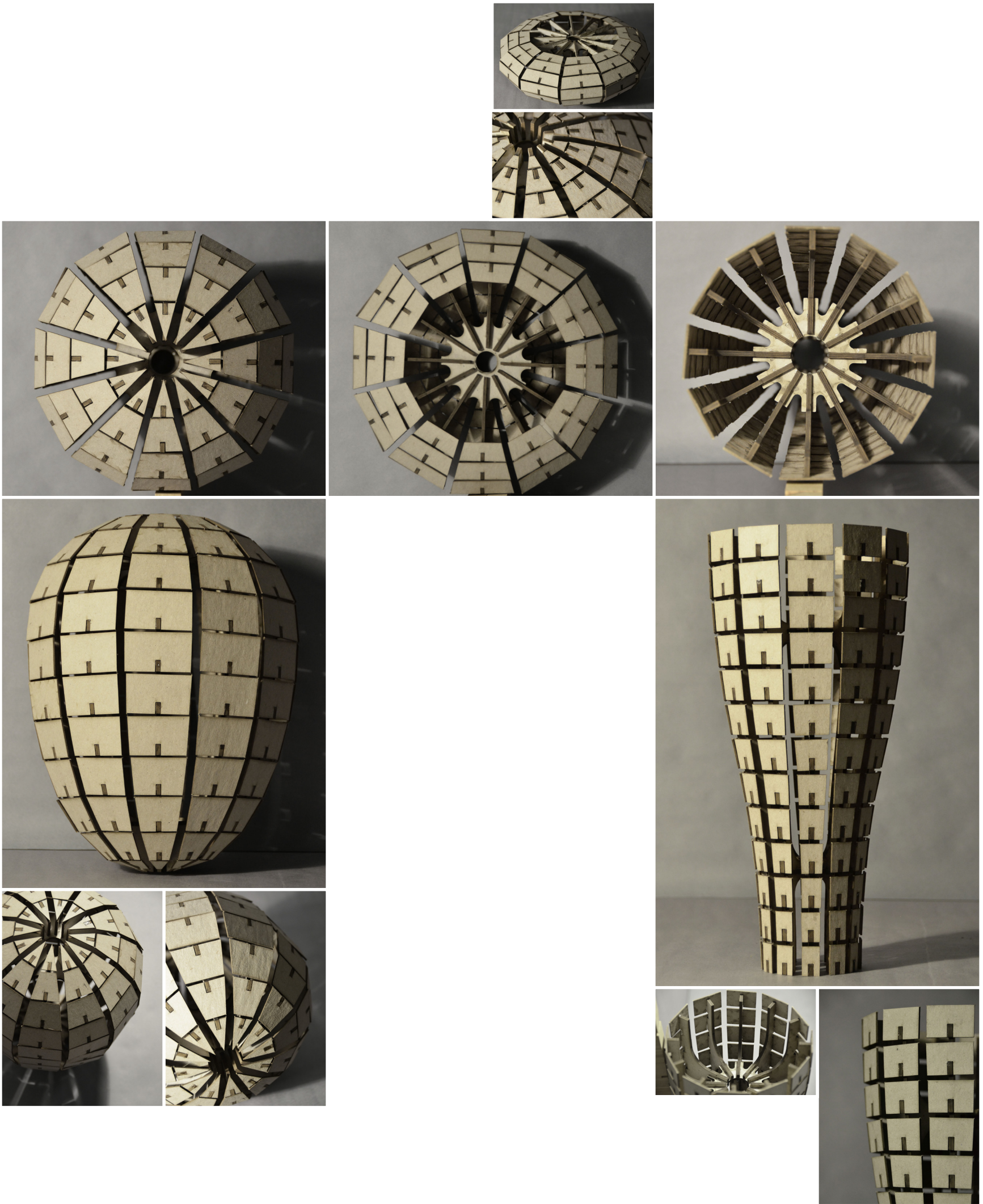
Chapter 2:
A study of a luminary object

This chapter will present a study of a luminary object that can change its light effect by an operable mechanism. As the operable mechanism is applied, the object gradually is empowered by energy, unfolds and releases the light.

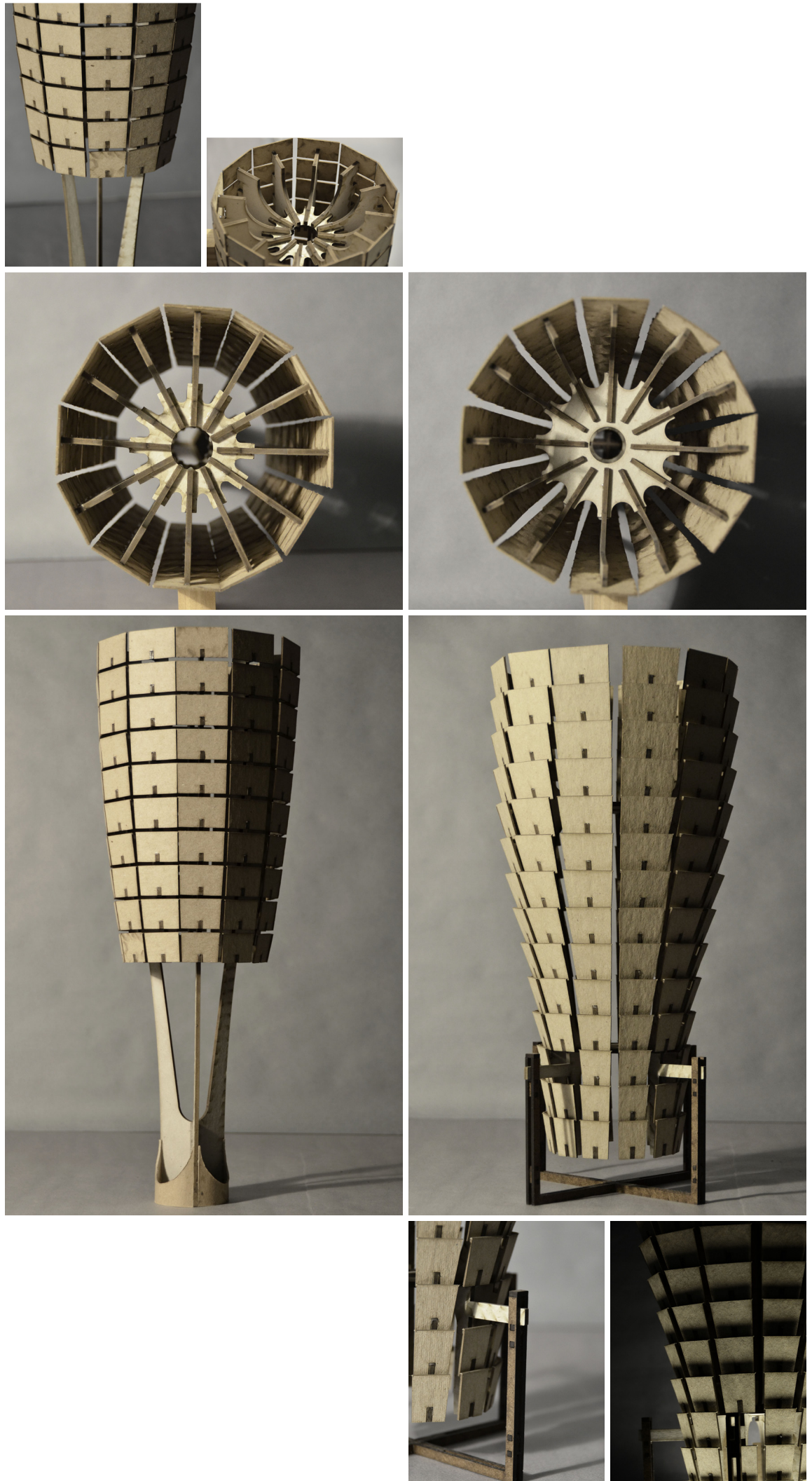
Study of the form and ornamentation

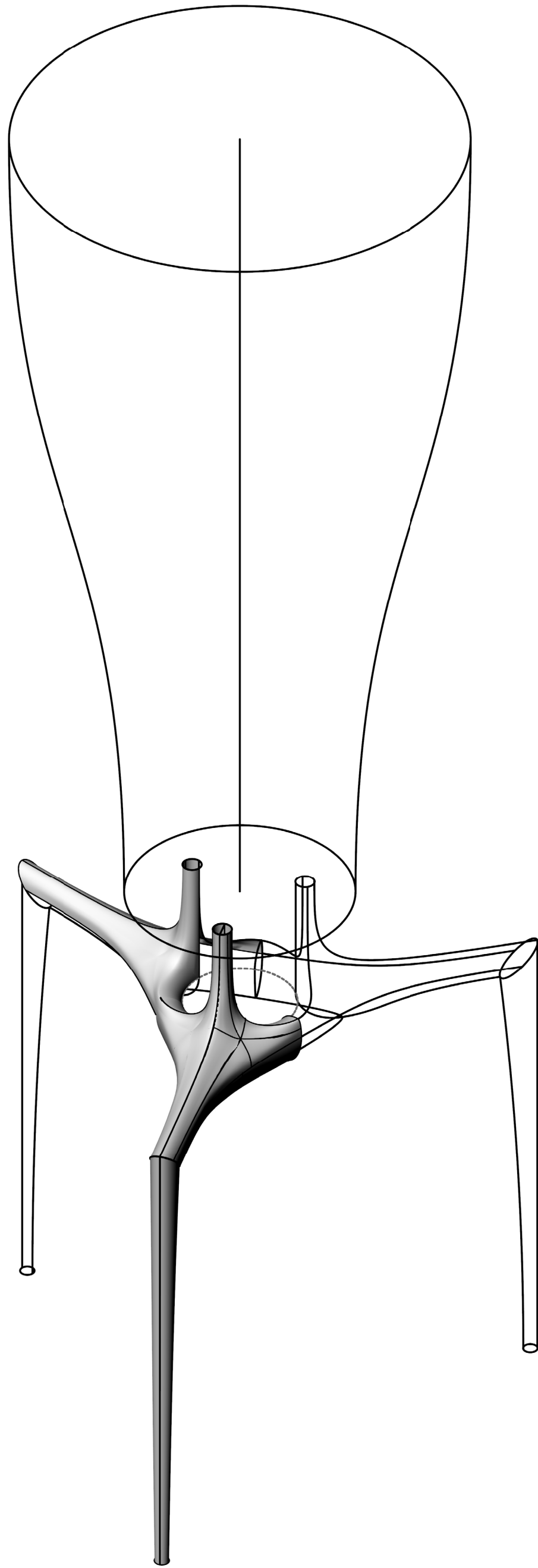


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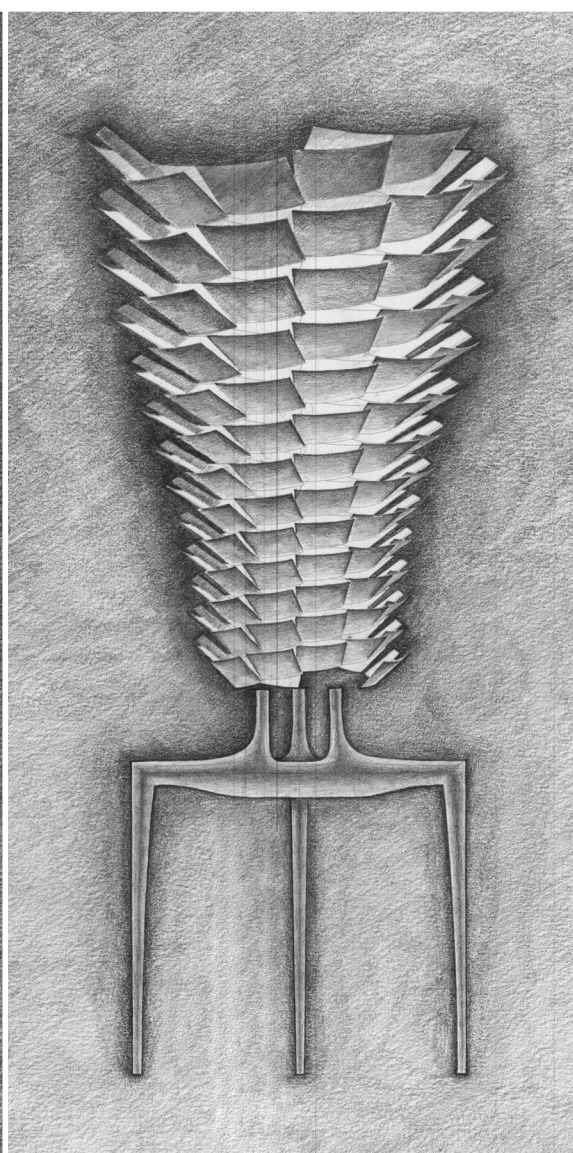
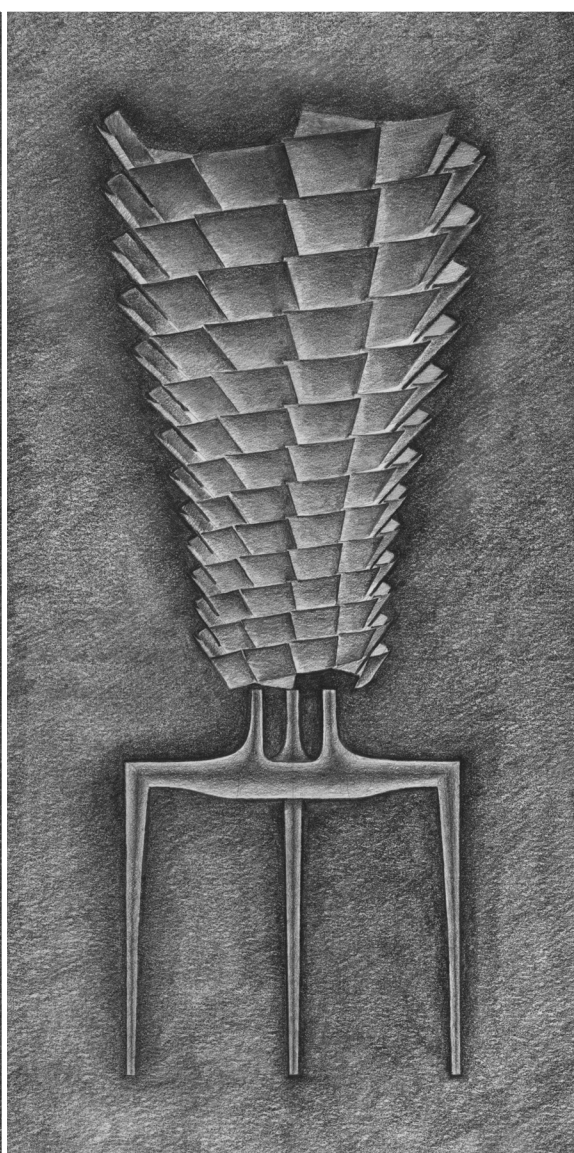
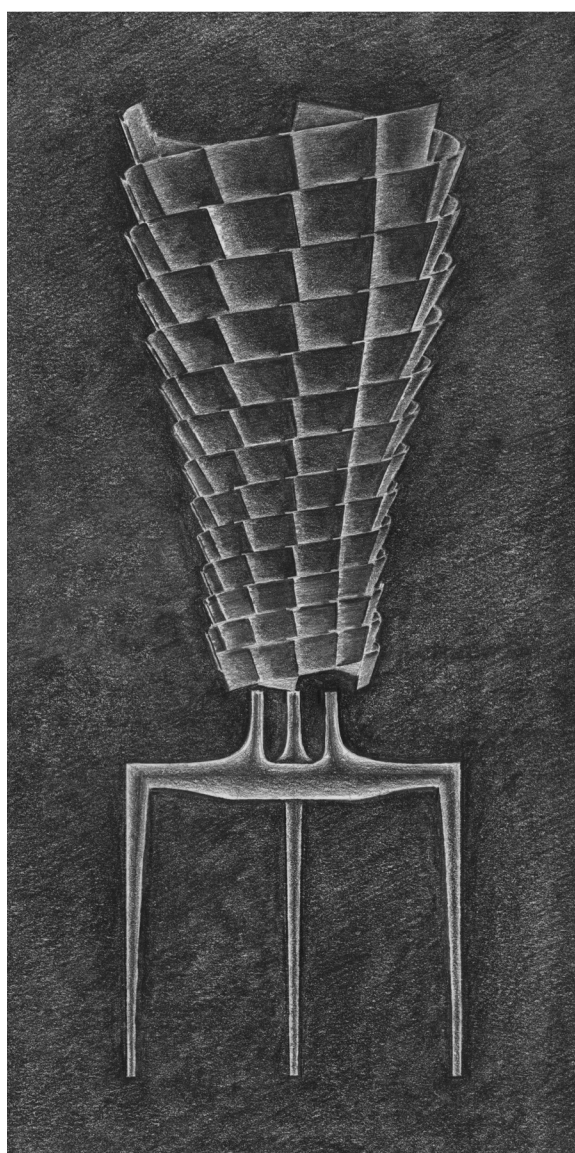


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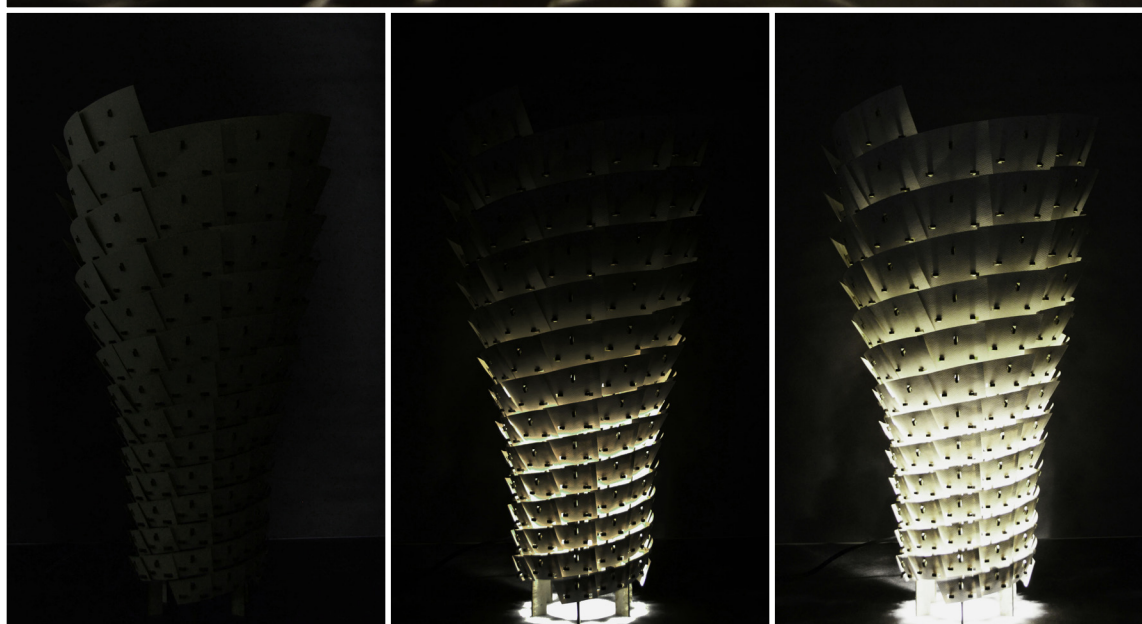
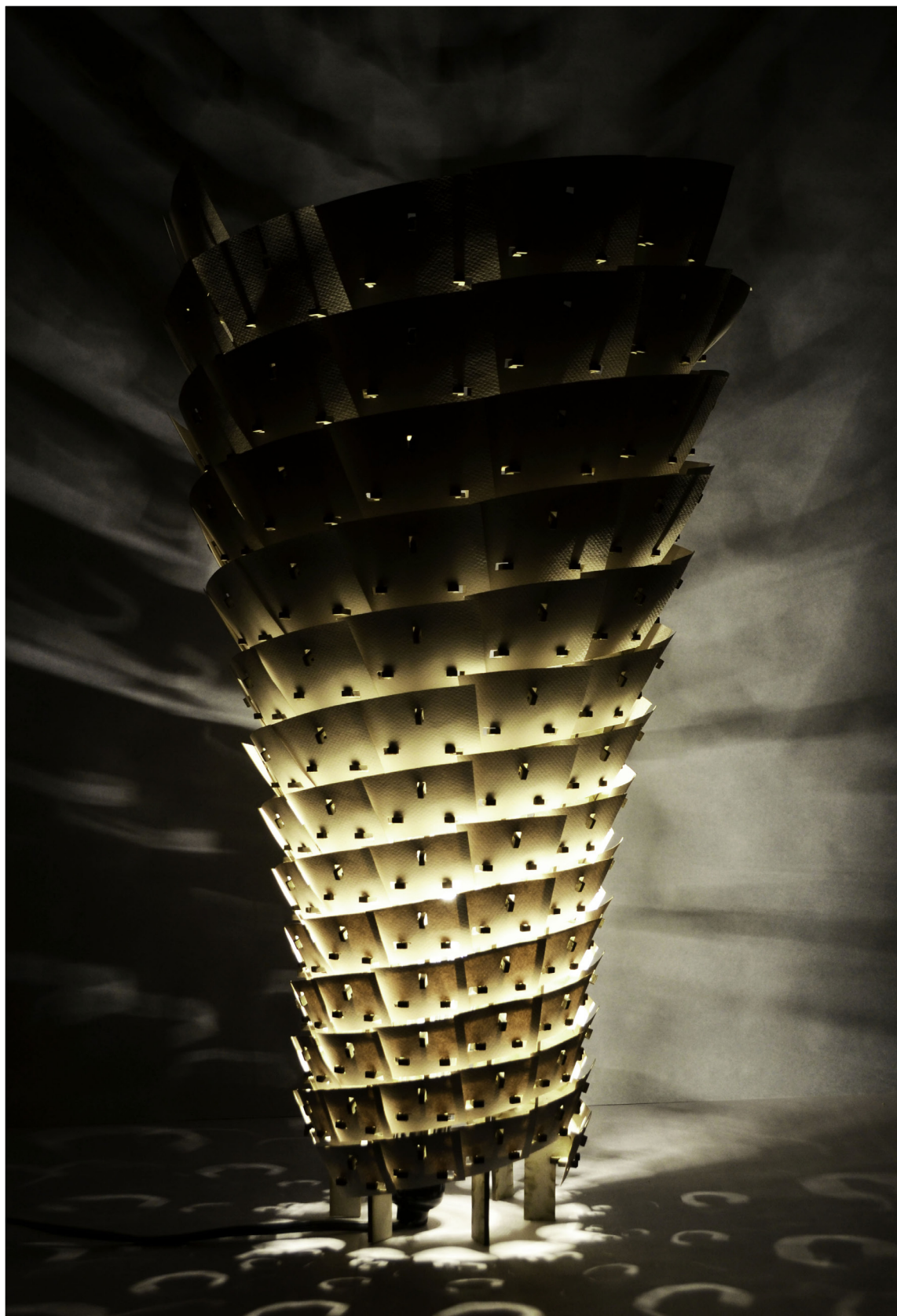




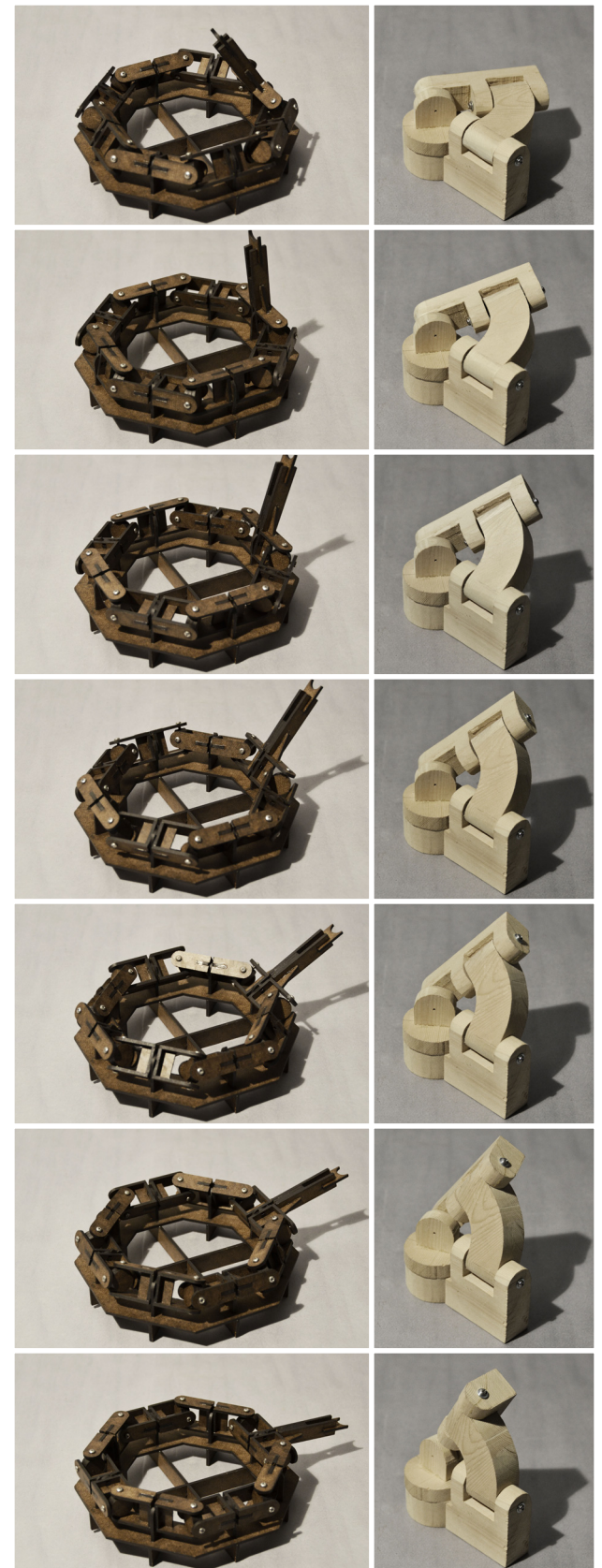
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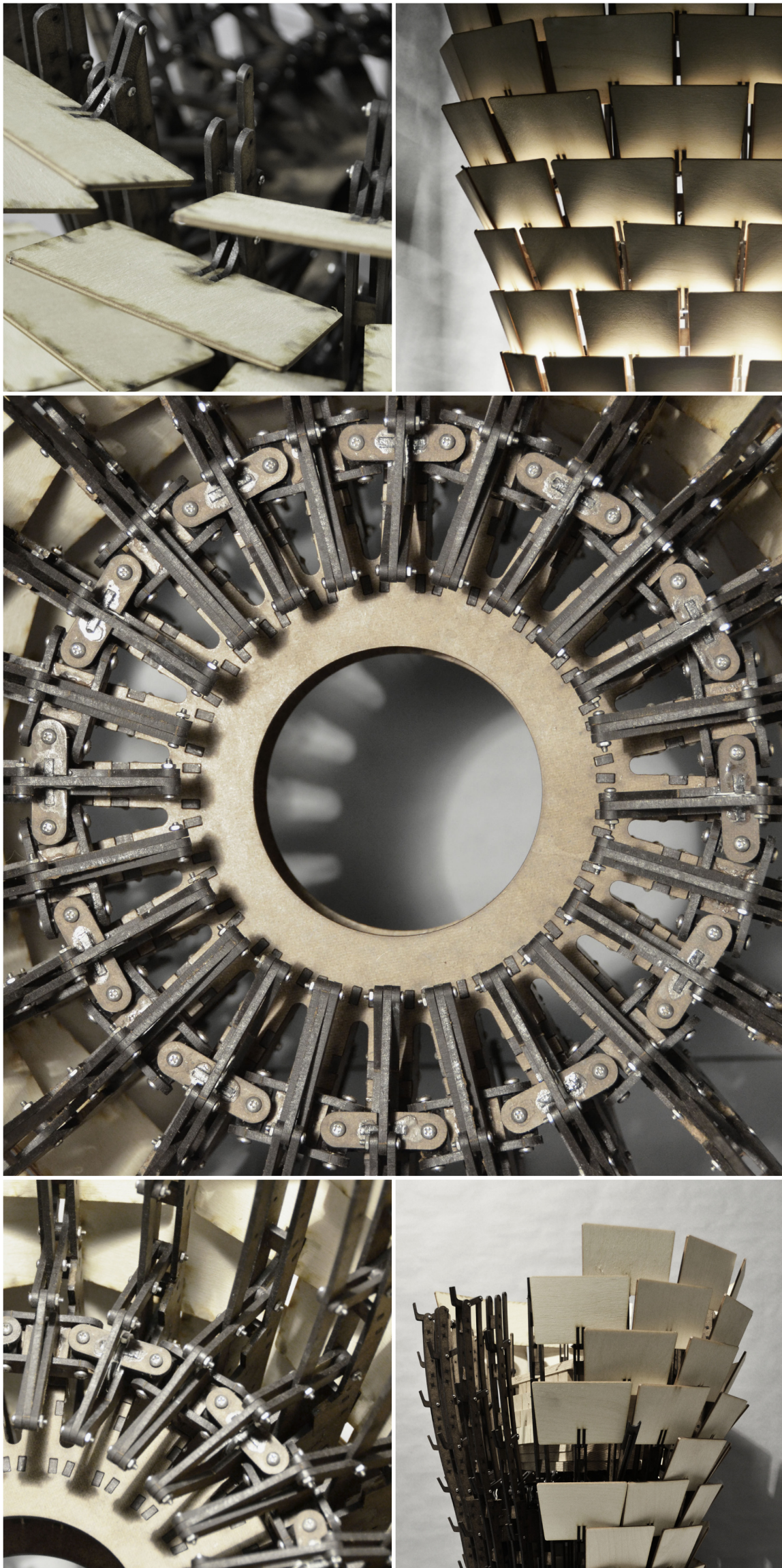
Study of Light



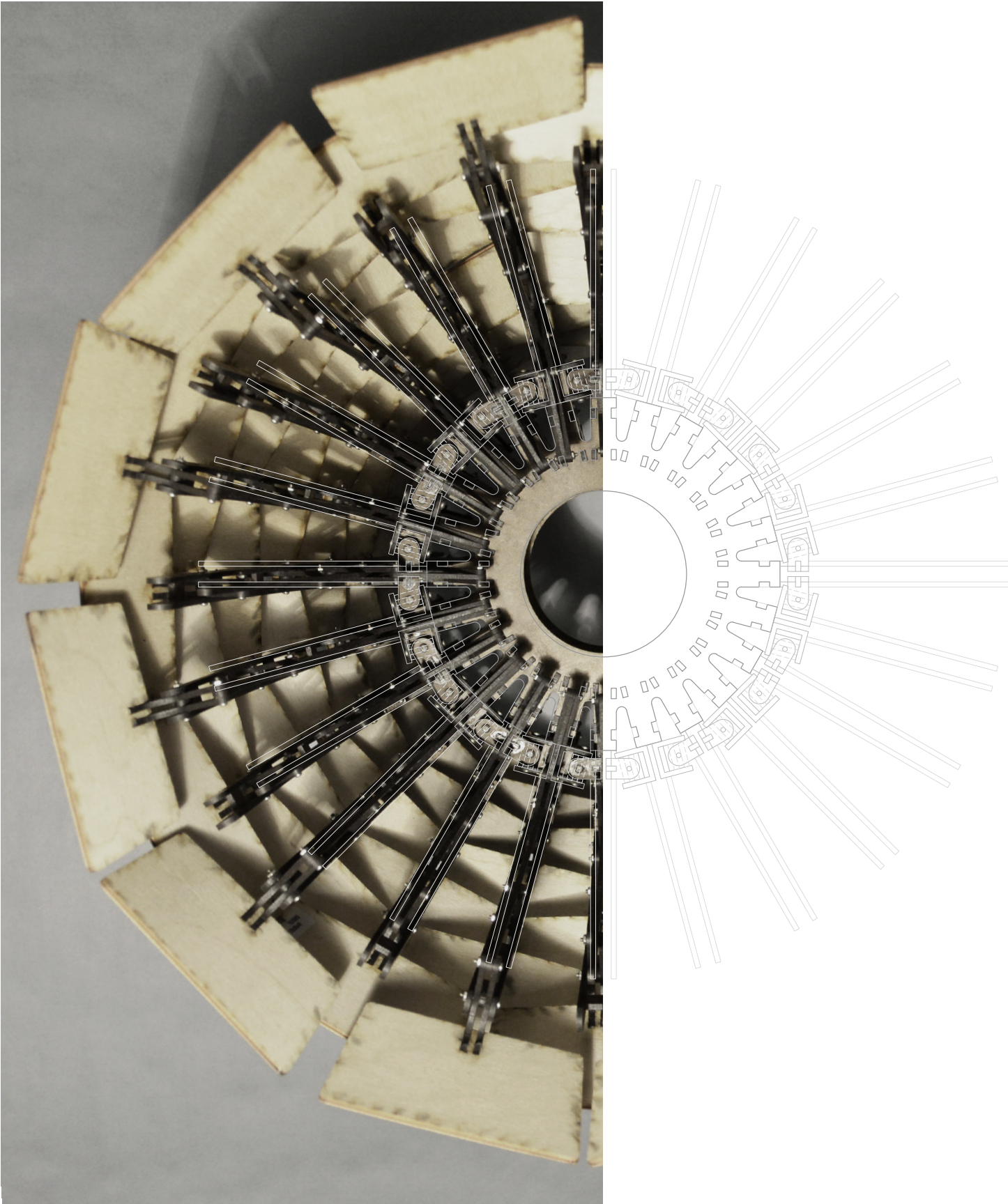
Study of the mechanism - Torus

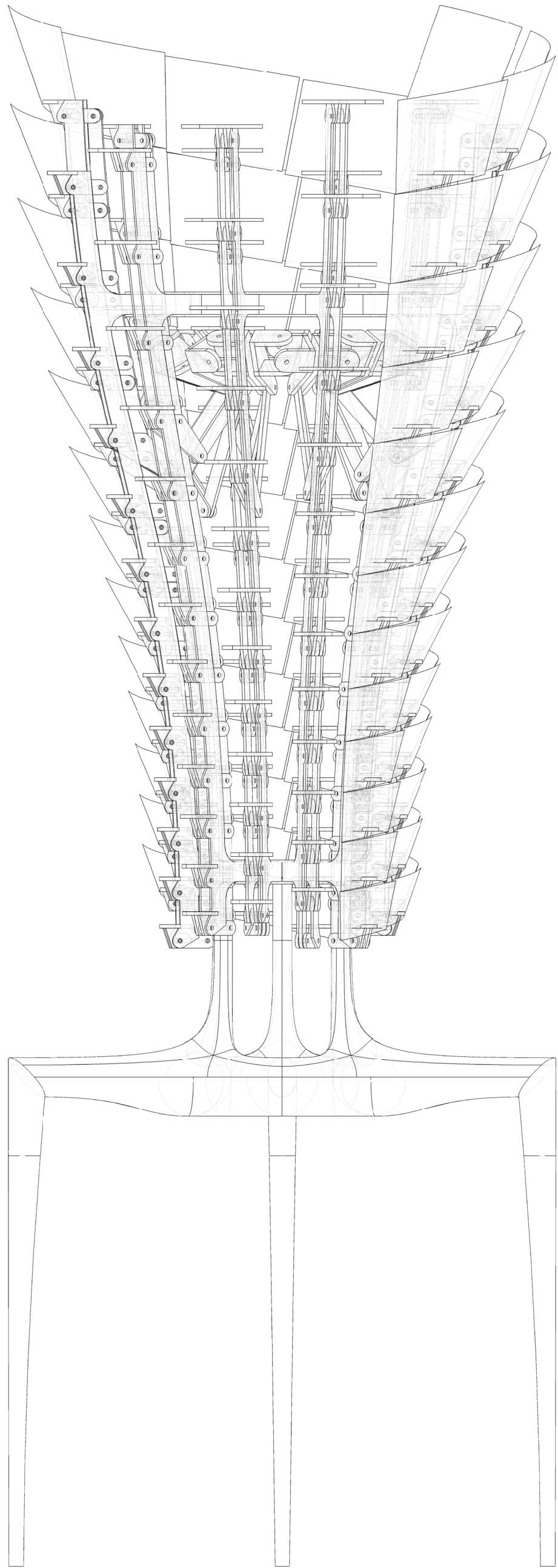


Study of the mechanism

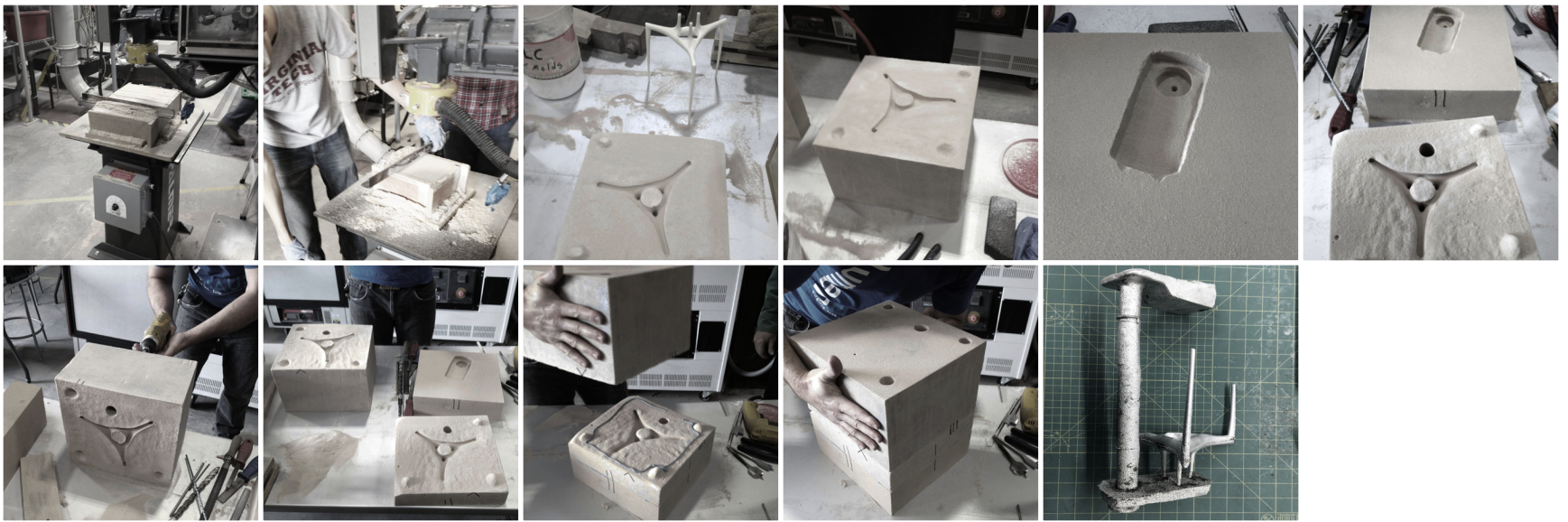


Study of the mechanism





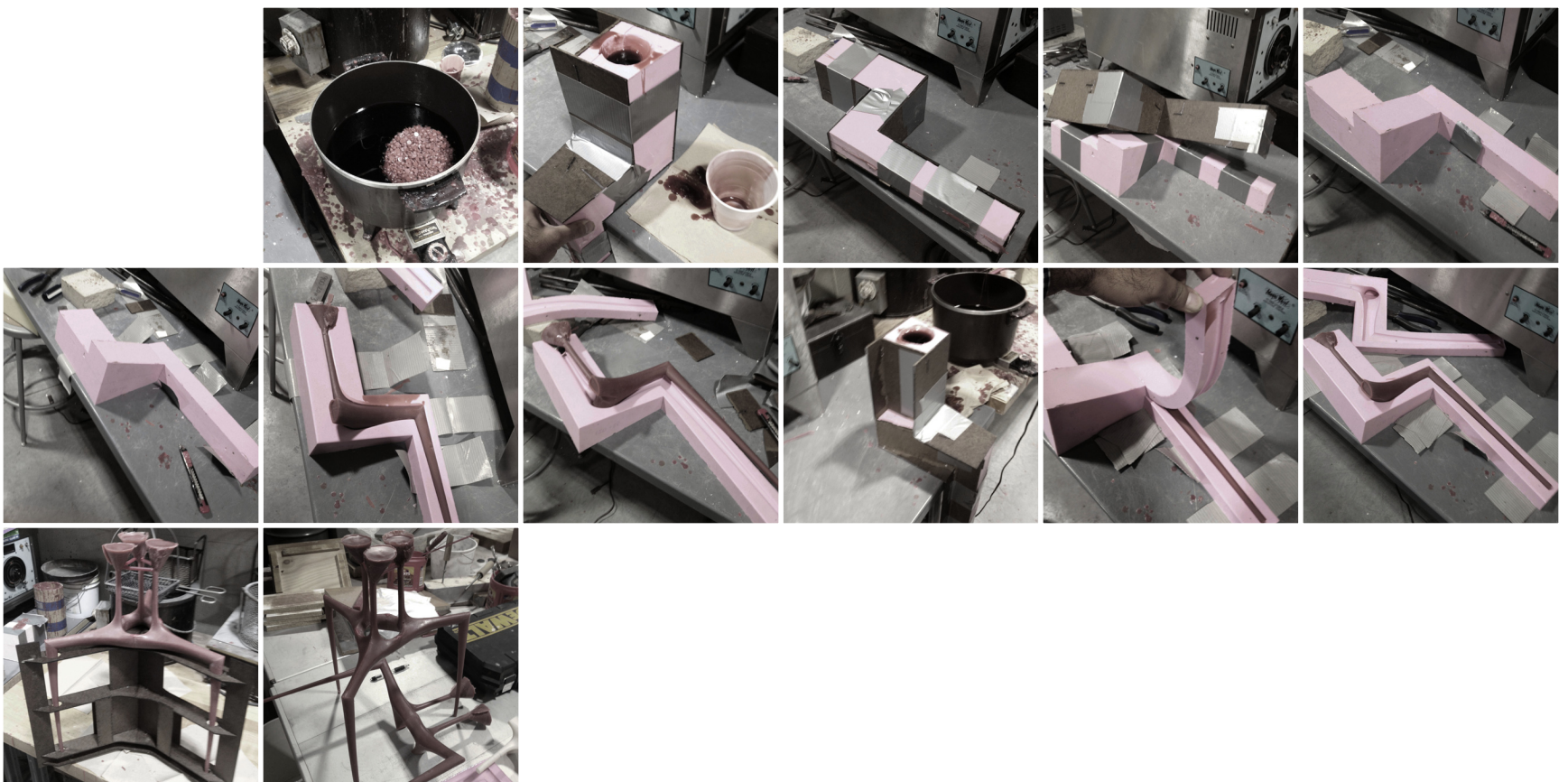
Casting the Base: Sand casting



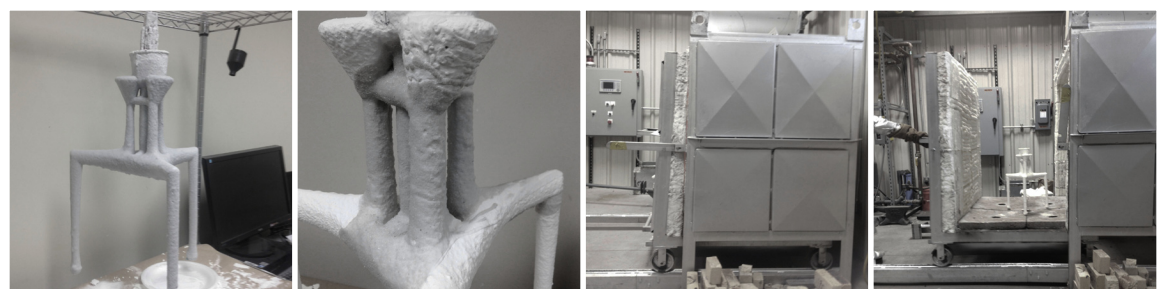
Casting the base: Lost-Wax casting - Preparing the rubber mould



Casting the Base: Lost-Wax Casting - Preparing wax pattern from the rubber mould



Casting the Base: Lost-Wax Casting - Adding the slurry layers to prepare the ceramic shell and melting the wax



Casting the Base: Lost-Wax Casting - Pouring, breaking the ceramic shell and preparing for assembly



Assembly

