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Deployable Scissor Mechanism for Responsive and Transformable Facade Design. (Case Study of a Structural Systems Course, Bachelor Degree Architecture Student, University of Tehran)

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Abstract

Architectural education prioritizes the cultivation of aesthetically pleasing, responsive, and sustainable designs to imbue future architects with environmental and social responsibility. Emphasizing the creation of adaptable spaces catering to evolving user needs and ensuring long-term usability is central. Technological advancements have profoundly influenced architectural pedagogy, prompting the integration of practical experience with emerging technologies to foster innovative thinking. A comprehensive workshop at the University of Tehran introduced undergraduate architecture students to Structural Systems, employing diverse educational methodologies such as:

- E-Learning
- Simulation Training
- Coaching and Mentoring
- Interactive Training
- Hands-On Training.

This holistic approach aims to foster creativity, integrate theoretical and practical knowledge, and equip students with the skills needed to navigate the complexities of architecture, encompassing design mastery, computer modeling, and the application of geometric and mathematical principles in structured programming.

Keywords: transformable, responsible, façade, scissors mechanism, training, architecture, morphology, form finding

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1. Introduction

In recent decades, architectural education has evolved significantly, focusing on integrating new technologies with traditional teachings. This evolution emphasizes moving beyond static architectural principles towards embracing adaptability, responsiveness, and flexibility in designs, aligning them with users' dynamic needs. Key considerations like climate, economics, geography, structural resilience, and complexity continue to be vital aspects of architectural learning. Researchers and educators contribute diverse solutions, drawing from various teaching methodologies and experiences across architectural institutions, aiming to harmonize theoretical knowledge with practical skills in students. Ultimately, architects must possess a comprehensive understanding of not just physical structures but also their functional and contextual aspects, reflecting the interdisciplinary nature of modern architectural practice. in the other words, "An architect should feel what is going on in a structure without needing to count it exactly." (Ilkovič, Ilkovičová, Špaček, 2014, p.59) In a study conducted in 2022 at Rice University School of Architecture in America, findings from two years of exploration highlight the benefits of incorporating physical and digital experimental structural models in architectural technology courses 1 and 2. These models positively impact students' comprehension of architectural structures. Additionally, this teaching approach enhances students' understanding of the interplay between static principles, material properties, and spatial qualities within a holistic design framework (Castellón González, [2]). Architecture encompasses more than just creating spaces or products; it involves a complex process of integrating variables, conducting data analysis, and applying geometric and mathematical principles using appropriate tools (physical models, digital and parametric modeling). This process aims to achieve structurally sound and aesthetically pleasing designs while considering form-finding based on the morphology of structures in architecture.

2. Transformable Architecture

Architecture that can change form is adaptive and responsive to contemporary needs. Transformability represents a form of change and movement. Alternatively, movement is a fundamental principle in design, evident in everyday objects like tents and umbrellas, which can be adjusted and controlled. Consequently, architecture functions as an environment capable of adapting to changes. On the other hand, flexibility, adaptability, and transformability in architecture have a significant impact on the creation of a sustainable built environment. (Kronenburg, [3], Christoforou, Müller, Phocas, Matheou, and Arnos [4]) It is important to mention that architecture, in addition to responding to the changing needs of users, aims to utilize minimal natural resources with maximum efficiency. This design approach should lead to the use of materials with suitable mechanical properties, lightweight, modularity, fast and easy connection, flexibility, changeability, and adaptability to existing conditions. By leveraging new technologies to improve spatial quality while using minimal materials and energy with maximum efficiency, this process results in adapting to users' changing needs, enhancing the building's aesthetics, achieving economic efficiency in construction operations, and ensuring safety in the work environment. Therefore, transformability and flexibility constitute fundamental driving aspects in enabling the enhanced properties of the building structure and its communication logic with the living environment. (Matheou, Phocas, Christoforou, and Müller [5])

3. Scissors Mechanism

As mentioned in the transformability section. The advancement of technology, limitations in construction, the increase in population, and the changing architectural and construction needs encourage the use of new methods and optimal use of space. From this procedure, architects and designers try to use new ideas and solutions to respond well to the needs of users and audiences. The scissor mechanism is one of these solutions. (Vojdanzade, Taghizade [6]) Scissor units consist of two bars connected by a revolute joint in the middle section of the bars. This joint, scissor or intermediate hinge, allows the bars to rotate around an axis perpendicular to their common plane. A grid structure that consists of linear or surface-like scissor mechanisms can be formed, which can be transformed from a compact bundle of elements to a fully deployed configuration, if we connect a series of scissors – like – elements (SLE) at their end nodes by revolute joints. The mechanism consists of the deployment phase to the service phase, in which it can be bars loads. The upper and lower end nodes of a scissor unit are connected by unit lines. Altering the location of the scissor hinge, intermediate hinge, or the shape of the bars gives rise to three distinct unit types:

- Translational (Figure 1)
- Polar (Figure 2)
- Angulated. (Figure 3) (De Temmerman [7], Mira [8])

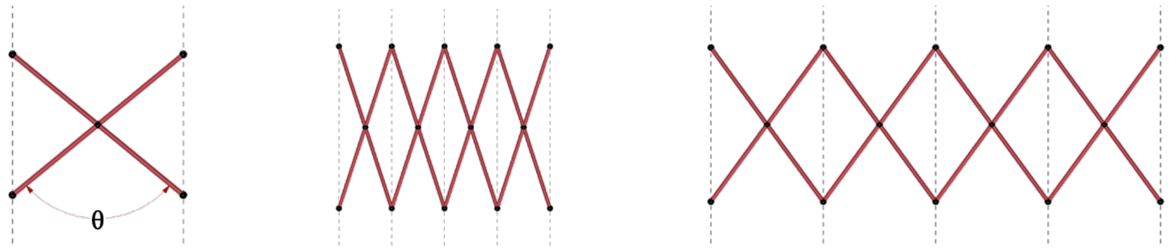

Figure 1: Translational unit

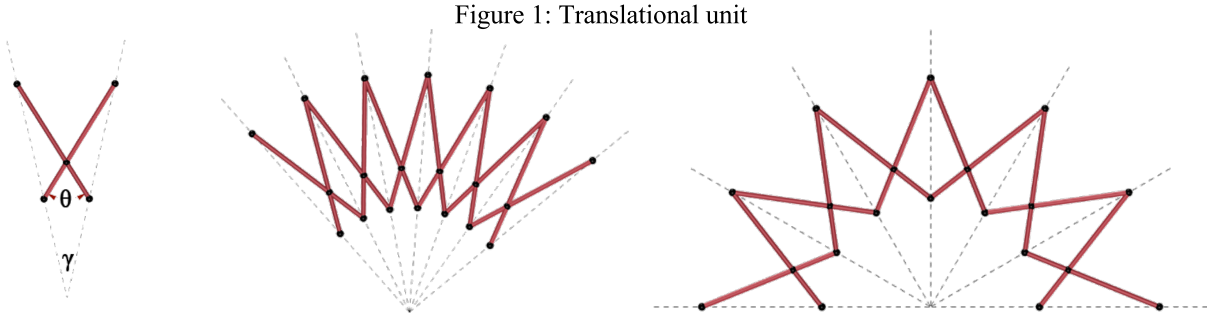

Figure 2: Polar unit

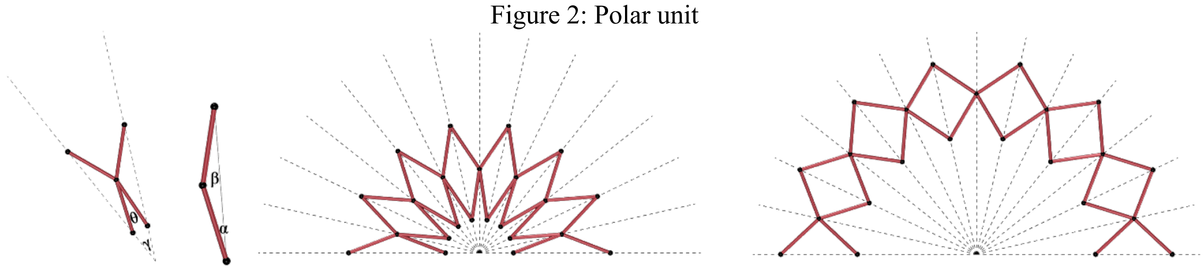

Figure 3: Angulated unit

4. Physical and Virtual Model

It is demonstrated that since the beginning of the twenty-first century, the primary functions of the architectural model intertwine with digital modeling for the most part. (Pushkareva, Ivanova, and Utkina [9]). Nowadays, contemporary architects often give up of utilizing physical handmade models, despite physical models are effective and prominent tools for creating, understanding, and explaining architectural design concepts. (Patre, Goray and Kapuganti [10]) This is due to the development of digital technologies that brought new techniques in architectural modeling and the presentation of architectural projects – for example, virtual 3D modeling visualizations or the use of Augmented Reality. However, physical 3D models still play an essential role, especially in architectural education. (Kamel, Khalil [11], K. Kristianova, Joklova, and Meciar [12]) The use of modeling is considered one of the suitable methods for comprehending the concept of structure. (Figure 4, 5) Modeling involves simulating environments with variable sizes, scales and materials compared to the real environment. It begins with selecting real environment components and abstracting their characteristics to create corresponding abstract entities. By establishing relationships between these abstract entities similar to those in the real environment, modeling accurately represents real-world scenarios. (Vojdanzade, Taghizade [12])

5. Form Finding

Form-finding in Architecture is a process to discover one or more correct ways which organized building according different items that optimize form with dynamic and static character to create responsible space with visually aesthetic. Form-finding processes in architecture can be categorized into six sections based on the main factor controlling the process. These sections help in understanding and organizing the various approaches to form finding.

- Topology Architecture Processes
- Shape Grammar
- Digital Morphogenesis
- Biological Processes
- Material-Informed Processes
- Algorithmic Processes

Form finding can be accomplished using software tools such as parametric software or through physical models. These methods play crucial roles in exploring and optimizing complex forms and structures.[13]

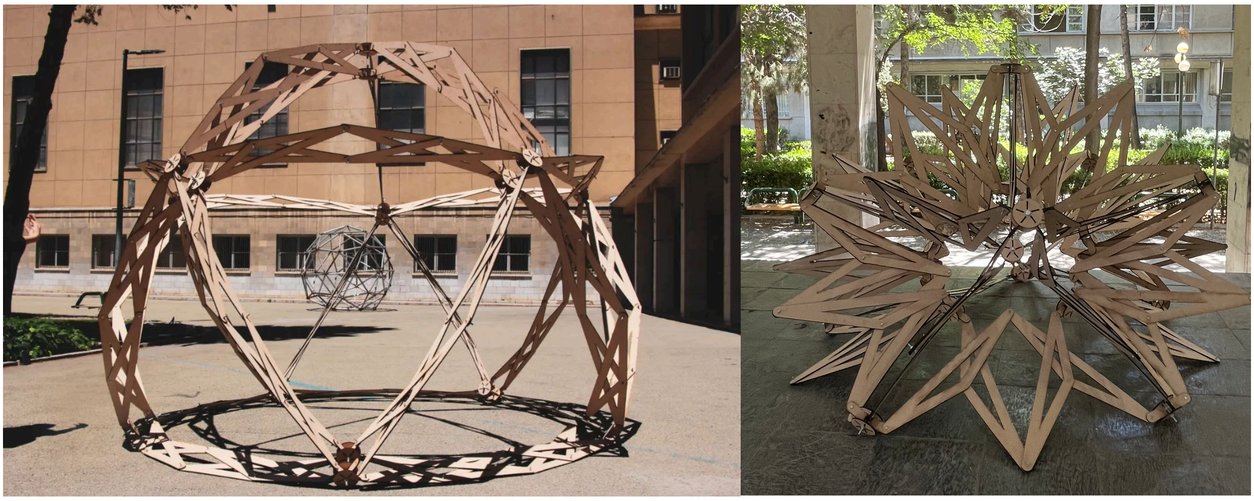

Figure 4, 5: Transformable Workshop, University of Tehran, May 2023

6.1. Mythology

This article aims to explore a novel approach to teaching the building system course in the bachelor's degree in architecture. The research involved 50 architecture students from university of Tehran organized into 10 groups of 5 individuals. The objectives were:

- Establishing connections between new technologies and topics taught in architecture schools.
- Shifting the teaching methodology from traditional static concepts to dynamic ones like transformability and adaptability.
- Addressing various considerations including climatic, economic factors, flexibility, and structural resistance.
- Proposing solutions for achieving balance and harmony between architectural design and structural elements.
- Emphasizing active student participation in problem-solving during the teaching and learning process.
- Implementing multiple student-centered practices.

6.2. Workshop Frame Work

The workshop offered participants a thorough understanding of the scissor mechanism, highlighting its three main components:

- Theoretical topics
- Practical topics
- Design and construction (Figure 6)

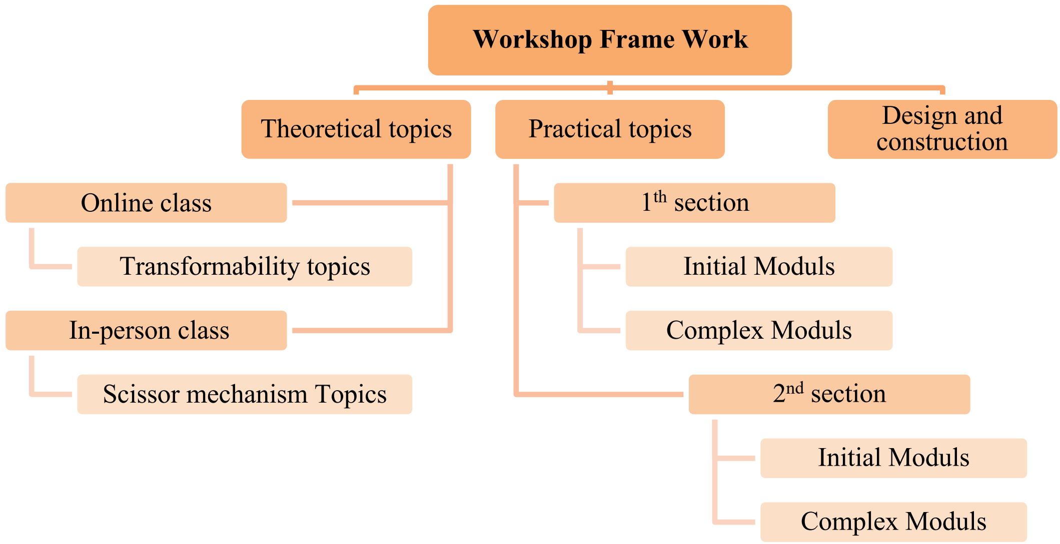

Figure 6: Workshop Frame Work

6.2.1. Theoretical topics

Theoretical discussions were conducted to explain the concept of transformability, classification, and the introduction of various mechanisms related to transformability. The necessity of utilizing these mechanisms was discussed in both online and face-to-face settings.

Online class

Concepts such as transformability, its infrastructure, types of transformability classification, and the necessity of using it, along with case examples, are included as headings in this section. (Figure 7)

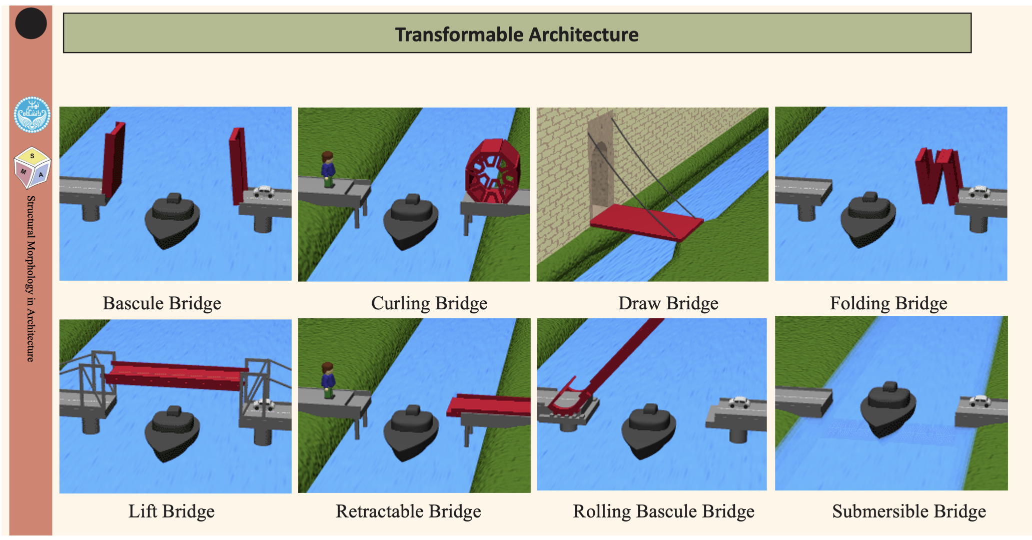

Figure 7: Online classes

In-person class

The listed contents cover essential aspects related to the scissor mechanism:

1. Understanding the basics of the scissor mechanism and its components

2. Exploring different methods and strategies for moving objects using the scissor mechanism

3. Examining the geometric concepts and principles crucial for the functionality of the scissor mechanism

4. Identifying the specific design criteria and operational behaviors required for effective scissor mechanism performance

6.2.2. Practical topics

The objectives of this workshop include gaining familiarity with the scissor mechanism, constructing various prototypes, understanding the characteristics of suitable materials, designing connections based on selected materials and the movement mechanism. The practical part of the workshop spanned two days (10 hours) during which students worked with proposed materials, creating multiple prototypes and mastering connection design through practical exercises. Students worked in groups of 5, forming 10 groups to create modules and prototypes.

- **First Part**

In the initial phase, the students studied basic transitional and polar scissor units using linear (one-dimension) elements and then applied this knowledge to create prototypes relevant to the course materials. They later expanded their understanding by designing a multifunction arch and a hyperbola that based on scissor mechanisms, showcasing enhanced skills and creativity. (Figure 8, 9, 10)

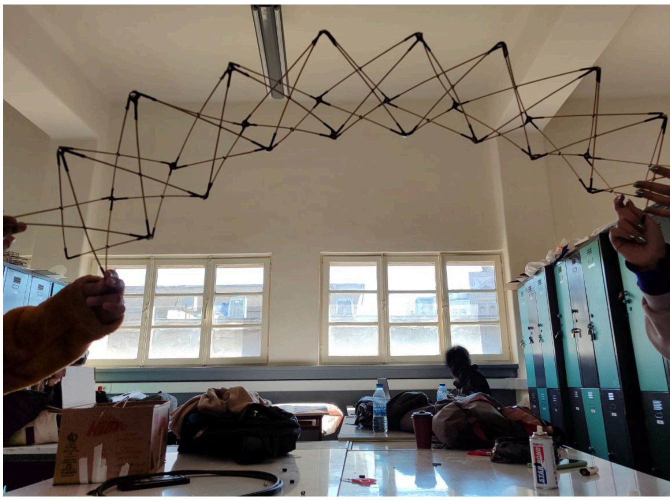
Figure 8: Polar arch prototype

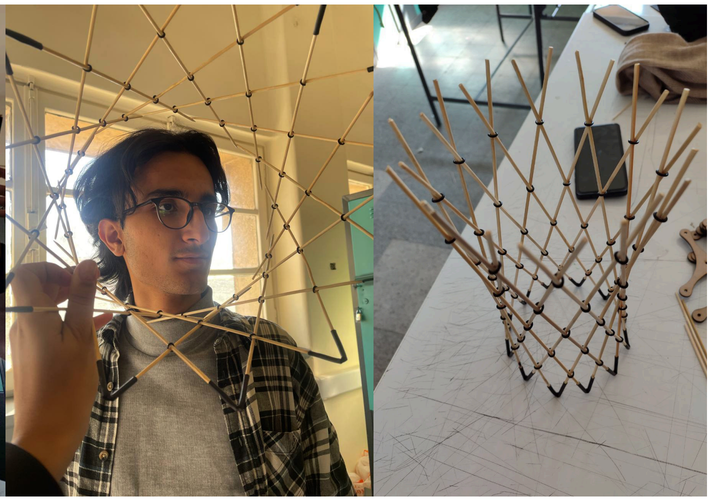
Figure 9,10: Hyperbolic prototype

- **Second Part**

The second phase involved creating angular and polar units using two-dimensional elements. Transitioning from one-dimensional to two-dimensional elements impacted the joints, construction techniques, and material requirements, enhancing the students' proficiency in crafting structural physical. (Figure 11, 12) The workshop's primary objective is to create functional prototypes for facades that can open and close, to meet users' needs. Hence, the modules developed by the students in the second phase were designed to fulfill specific goal. (Figure 13, 14) During the ongoing training, students constructed prototypes incorporating the functionalities of bridge units, pavilions, mobile structures, and structural facades. Additionally, they delved into creating new prototypes by extending and integrating fundamental design elements. (Figure 15)


Figure 11: Polar arch prototype fabrication


Figure 12: Angulated prototype


Figure 13: Prototypes fabrication


Figure 14: Prototype fabrication


Figure 15: Prototypes fabrication

6.3. Design and Construction Process

Following the workshop's division into practical and theoretical phases, students faced to a challenging design and construction a project aligned with the workshop's main goals. As a result, they successfully completed and delivered 10 projects as part of their learning experience.

6.3.1. Design matter and requirements

Designing and building a prototype based on a scissor-like mechanism with the ability to open and close, so that after opening, it can be placed and fixed within a square frame measuring 50x50 cm.

6.3.2. Design Process

Based on the topic, the students spent four weeks designing the proposed prototype of the transformable facade based on the scissor mechanism. They try to achieved appropriate form. (Form Finding) During this period, the students were in online communication with the workshop instructors, and two correction sessions were held online for the students to discuss the challenges they faced in the design and construction process. (Figure 16, 17)

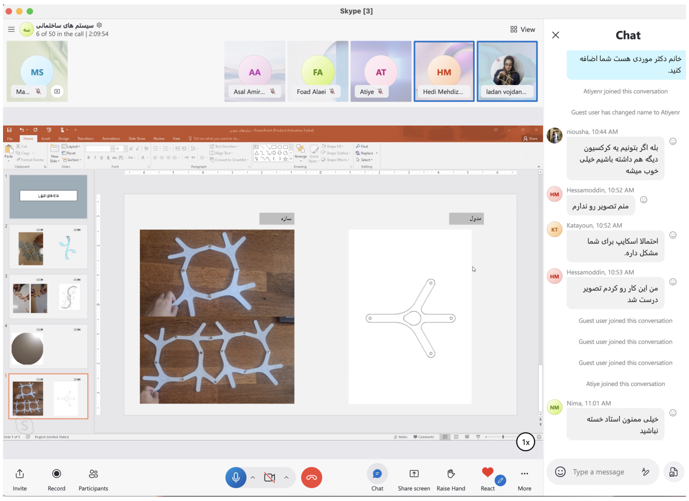

Figure 16: Online corrections

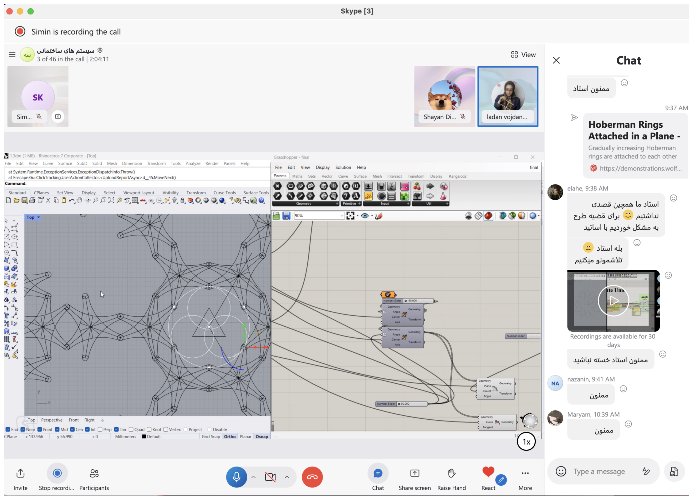

Figure 17: Online corrections

Students should pay attention to the following aspects when designing the scissor mechanism:

- Location of members
  - Position of nodes and connections when the structure is closed.
  - Position of nodes and connections when the structure is open.
  - The position of nodes and connections during the process of opening and closing.

- Members’ movement direction
  - Movement direction of nodes, connections, and members during the opening and closing process

- Range of motion in component operation

6.3.3. Students' challenges in the design and construction process

- According to the workshop's educational topic, the section on algorithm writing for the scissor mechanism was not presented to students. (This decision was made due to not all students being fully familiar with modeling software such as Grasshopper.)
- Some students used parametric software such as Grasshopper for the optimal design of complexities in the design process. Simultaneously, while the students were designing and refining their proposed plans, the algorithm for the scissor mechanism was developed with the guidance of the teachers.
- Design based on geometric, trigonometric, and mathematical principles is essential in computer design, where the use of mathematics and geometry is inevitable. Students utilized these principles in the design and construction process.
- Designing the details of connecting the prototype to the defined frame (50 x 50 cm)
- Choosing the appropriate materials
- Covering parts of the prototype with the proper cover
- Designing the mechanism to open and close the cover simultaneously with the scissor-like mechanism prototype's movement, to ensure it does not prevent its movement.
- Designing the method to connect the cover to the scissor’s mechanism elements. (Figure 18)
- the process of designing and fabricating connections using specific materials
- Generating the motion path of prototype (Figure 19)

Figure 18: Connecting the cover to SLE

Figure 19: Generating the motion path

Figure 20: Final Prototype

7. Conclusion

Based on problem-solving learning, students successfully presented the design process and implemented it effectively in their group work. Despite encountering numerous challenges, they strategically provided suitable solutions and achieved the workshop's specified goals. (Figure 20) On the other hand, the use of structural physical models in different scales facilitated students' understanding during the design and implementation process. Utilizing diverse structural models allowed them to comprehend how force transfer occurs within a structure and gain insight into structural behaviors.

The use of these two methods together improved the abilities and skills of the students. The results obtained from the produced product demonstrate that integrating problem-solving learning with the construction of physical structural models significantly impacts the teaching and learning of architectural structures, preparing students to work in professional environments. Essentially, learning naturally evolves from active participation. The outcomes of this workshop can be categorized as follows:

- Increasing understanding of scissor mechanism principles and their application in architecture and engineering
- Creating physical prototypes to apply theoretical knowledge practically
- Exploring different configurations of the scissor mechanism and their compatibility with architectural designs

- Understanding structural stability and safety considerations in architectural projects using scissor mechanisms
- Encouraging design innovation by tasking participants with scissor mechanism-based solutions
- Promoting teamwork through group projects involving scissor mechanism-based structures
- Developing communication skills and collaboration in group settings
- Gaining practical knowledge of scissor mechanism applications in real-world scenarios

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