Necessity of using Problem Based Learning (PBL) and Structural Physical Models on an Educating Structural Course: Case Study of a Structural Systems Course, Master Degree Architecture Students

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Abstract
Teaching structure to architecture students is an important part of the architecture curriculum in faculties. Weak points of architecture students in using their knowledge and data in real environments has caused many problems in professional activities or withheld their essential skills. In this situation they cannot use their abilities and success in their job positions. In this study, we aimed to promote learning structural behavior in a structural systems course, by using a method that is a blend of a Problem Based Learning (PBL) model and a physical model. This was undertaken in structural studies for master degree students in the University of Tehran. In the recent experiment, the theoretical class changed to a workshop and practical class and they learned and studied by working in a group and through hands-on activities to increase their skills and demonstrate abilities, so they are prepared for parallel situations in future. The research method which has been used in this paper is based on the description of the subject feature. According to the research, a PBL model and Structural Physical Model are appropriate ways of understanding the structural behavior without using complicated mathematical formulas. It also provides the best technique for students' preparation and learning.

Keywords
Structural Physical Model, PBL, Structural Design Training, Deployable Pavilion, Educating, Teaching Methods.

Introduction
In the past decade, there is a new orientation to teach theoretical and lecture based courses such as structure with a similar approach and activities. Learning architectural design is usually a cooperative and problem based activity. (Khodadadi, 2015) Several researchers and teachers have tried to present perfect solutions based on different learning theories, teaching methods and experiences in different faculties of architecture.

In research, Dytoc (Figure 1) focuses on alternative teaching methods of illustrating structural behavior and concepts for integration into architectural design thinking. To reach this state, the pedagogic gap between architectural and structural classes needs to be bridged. The teaching methods are based on two viewpoints:

1. To comprehend structures in a graphical manner
2. To understand structures as a potent sculptor of form. (Dytoc, 2009, p.51)

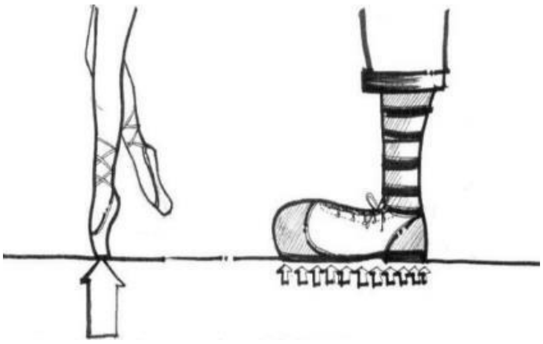


Figure 1: The ballerina, with her pointe shoes, balances on her toes, while Bozo, with his huge size 20-EEE wingtips, flip-flops his way to infamy. (Dytoc, 2009)

Raut and Kalamkar teach structures to architectural students in an innovative and interesting way through model making. The students' outputs are presented and this technique of model making hence is proved to be an effective method for practical understanding of structures concepts. (2019, p.4571) They design and create:

- A Model of Cable-Bridge to understand cable as structural member to take, divert and transfer load.
- A Model of Arch-Bridge to understand arch as member to take and divert load in structure.
- A Model of Truss to understand vertical, horizontal and inclined forces.
- A Tall building to understand wind forces   second article.

In the other research, Black and Duff (1994) used advanced structural engineering software, finite elements, to teach structures to architecture students. Students used the computer software to analyze small and large buildings and compare those with their hand calculations. According to Wetzel (2012, p.107), "integrating structures and design encourages students to inform their design decisions with an understanding of material properties, structural systems." Therefore, Wetzel introduced dynamic modeling techniques and large-scale installations to help students visualize structures and integrate structural systems in their design studio.

Callahan, Shadravan, Obasade and Hasenfratz believe that all programs of architecture focus on structures as independent coursework, rather than on integrating pedagogy. To fill this gap, an innovative freshman workshop was developed in a study with a student-centered active learning approach to teach structures. The results show that this method was a fairly successful structures introduction into architectural form, not previously considered. (Callahan, Shadravan, Obasade & Hasenfratz, 2019)

Generally, an architect must be able to conceive and visualize the structure of the building. [1] "An architect should feel what is going on in a structure without needing to count it exactly." (Ilkovič, Ilkovičová, Špaček, 2014, p.59) .One of the methods is to construct Structural Physical Models on a real scale. Severud (1961) points out that an education in structures should be addressed by a direct approach to "build a structure and destroy it and then see what happens: this is by far the best means of recognizing what goes on." (Emami, Buelow, 2016, p.2).

Structural physical models give students the opportunity to observe the process of destruction or alteration of structure, by building and applying forces multiple times, so that they can get a proper insight into the behavior of the structures. On the other hand, in teaching process of such a course, the active participation of students is very important and necessary. The student-centered approaches should be replaced by theoretical and teacher-centered approaches that, through their study time, provide information and practical skills to prepare students for future professional activities.

Generally, architecture has been comprehended as permanent structures. Reasons for this can be explored in an architecture's and designer's desire to design and manufacture building with a long life. Sculptural and monument buildings are the result of this viewpoint. So, these buildings could not change, alter or expand in future. It is apparent that the monument syndrome of static, permanent architecture has continued throughout history into our dynamic times of modern society (Korkmaz, 2004). Therefore, it can be concluded that not much attention has been paid to the development of motion-based techniques in architecture and this is an agreement that has been made between architects and society that has introduced the architecture as immobile, and this is static.

Charles Darwin suggested that the problem of survival always depends upon the capability of an object to adapt in a changing environment. This theory holds true for architecture. In recent years, there has been a growing interest in kinetic design. Architectural applications in responsive kinetic designs arise from issues of spatial efficiency and adaptability. An adaptable space flexibly responds to the requirements of any human activity. Adaptability may range from multi-use interior re-organization to complete structure transformability. Kinetic function in structures provides that the objects in the built environment are physically present only when they are necessary, and disappear or transform when not needed. This is to suggest that a new aesthetic, a new concept of form, is inherent in responsive architecture. (Korkmaz, 2004). Therefore, a constantly changing architecture is needed, a new type of architecture – transformable architecture- that is responsive to the essential characteristic of how our societies "change". Transformable, kinetic, deployable, adaptable, is an extended vocabulary to refer to a building with movable parts or a shape change. Transformable architecture has been used thought out history and continues. It adapts to new uses, responds to change rather than stagnating, and is mobile rather than static. Understanding how it has been conceived, designed, made, and used helps us understand its potential in solving current and future problems associated with technological, social, and economic change (De Temmerman, 2007).

1 - Structure of a building is the regular flow (or controlled) of the physical forces that pass through paths in the presence of robust materials to form a stable three-dimensional space. (Golabchi, Taghizade, Golabchi, 2015, p.31)

The main purpose of our research is based on using Structural Physical Model and Problem-Based Learning so that students can design and build a real-world project, in groups, according to architectural knowledge and creativity with perception of structure behavior and no need for complex numerical calculations.

In this regard, we are going to answer this question: whether the Structural Physical Model along with Problem-Based Learning can be used as a method to understand the behavior of the structures. In this article, after a short review of learning models, we will explain the lesson plan presented and probe the process of students' work.

Teaching structure in architecture

There are different questions in teaching structure to architectural students:

- How to teach a student to understand construction?
- How to perceive construction?
- How to solve construction problems in architectonic pieces?

As Ove Arup stated: “Engineering is a creative activity involving imagination, intuition and deliberate choice, it is exactly what should a student – architecture understand.” (Jones & Ove Arup, 2006, p.258) In the process of training, the teacher is searching for innovative manners to change students’ perception of the environment and enhance it, so that students can provide suitable and responsive space for users. At first glance, we couldn’t find architectural beauty in numerical and mathematical calculations, but these calculations can be presented geometrically and practically with the help of the perception and visualization of students.

A famous picture of Scotland’s Forth bridge shows a direct physical experience with a static principle of construction (Figure 2) (Ilkovič et al, 2014)

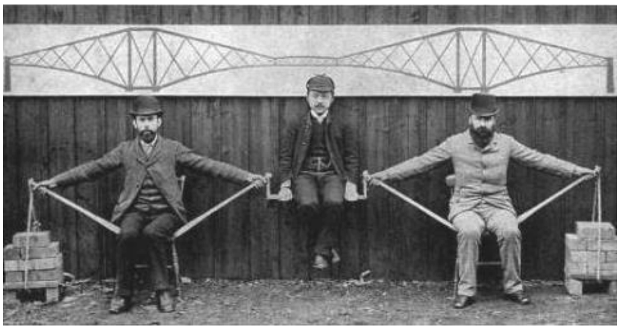


Figure 2: Living Model Illustrating principle of the Forth bridge. (Wikipedia, 2020)

Visualizing is easily acceptable and transformed through visual suggestion and students can receive a physical advance in their concepts of construction. Other examples of practical transfer of force include the idea of scissors-like elements bridge that Chikahiro, Ario & Nakazawa designed and built or scissors- like elements deployable bridge competition in Iran. (figure 3,4)

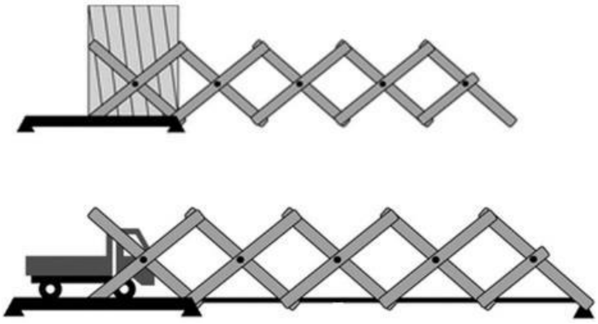


Figure 3: Deployable Bridge Idea (Chikahiro, Ario & Nakazawa, 2016, p. 04016051-2)

Figure 4: Scissors-Like Elements Deployable Bridge Competition- Iran

The Proposed Methods of Structural training for Architectural Students

Problem Based Learning

There are different ways of teaching. One of them is the Problem Based Learning[2] (PBL)[3] (Barrows, 1996). Ilkovic has developed this method and presented it as problem and project based learning (PPBL)[4] ((Ilkovič et al, 2014, Severud, 1961) which is a student-centered and active method, so it contrasts with the teacher-centered method. Problem Based Learning is defined as a high-level process of recognition that requires the use of coordination and control of desirable basic skills. In general, the very important purpose of Problem Based Learning is to make students use their knowledge in real environment in future. It happens in the following ways:

2 - In this method, learning is in the context of research and leads to continuous learning. At first, the teacher sets the problem, then students will collect information. So they present a hypothesis which based on information and finally conclude.

3 -The PBL process was pioneered by Barrows and Tamblyn at the medical school program at McMaster University in Hamilton in the 1960s.

4 - The PPBL method allows students to upgrade their management, planning and self-control capabilities. This method promotes cooperation, responsibility, discipline, patience, tolerance, and other students' basic skills in team working.

- Regular learning of knowledge
- Development of logical and critical skills
- Motivation for continuous learning
- Knowledge and skills Development by team work (communicative skills)

The teacher sets a problem in an assignment, which is solved by relying on previous knowledge, new data, using individual and group abilities and also guidance of the teacher. In teaching studio creation, methods based on problem or project teaching should always be applied and, eventually, as a combination of problem and project teaching. (Zelina, 2000) In both methods, students do their project as team work, which increases the sense of cooperation and teamwork.

Physical Structural Model

Perceiving the behavior of structures during loading can be achieved without the need for any calculations. Answering to questions about structural behavior could lead to perceiving structure. In indeterminate structures, which cannot be fully analyzed, such as Nervi's Aircraft hangar, using perceiving the structure will be an appropriate solution[5]. (Golabchi, 2008) (Figure 6, 7)

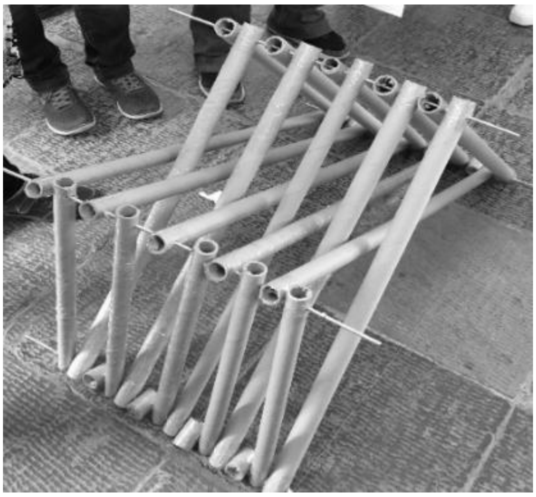


Figure 5: An Example of Structural Physical Model – Deployable and Transformable Chair (Taghizade, Vojdanzade, 2017, p.115)

> *In architecture, modeling is an omnipresent element in the design process; be it in the form of a rough sketch, an inclusive diagram, material artefact, a digital object or a numerical definition. Also in architecture education, the physical model, in particular, has a significant place in the student's toolset, not only as a means of (re)presentation, but as an indispensable medium capable to perform a dual role: resuming and reflective (analysis) or generating and productive (synthesis). (Zurich, 2015, p.4).*

5 - Nervi estimated amount of stress and determined the sizes through simple calculations, sensory and visual reasons and he proved that these dimensions were identical with the structural analysis of the test samples.

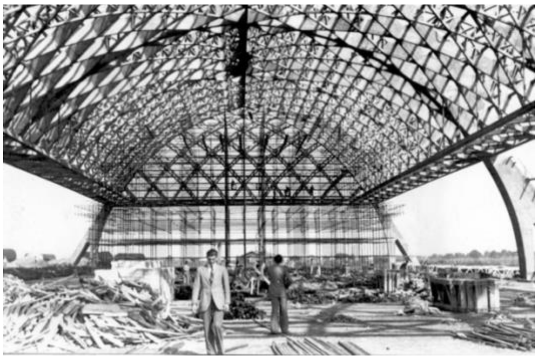


Figure 6: Nervi's Aircraft hangar (BMIAA,2017)

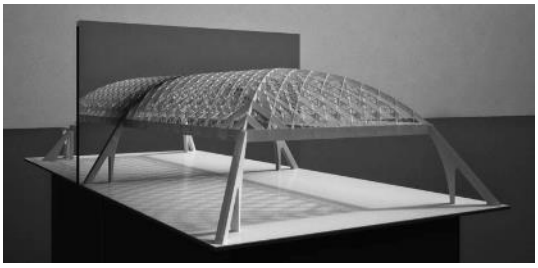


Figure 7: Nervi's Aircraft hangar model, the model as a tool of design and construction (BMIAA, 2017)

Therefore, Structural Physical Model is one of the effective methods for perceiving the structure. In general, modeling is the simulation of an environment of different sizes according the real world and in some cases with different materials.

> *In modeling, at first, the real environmental components are selected based on proportional specific purposes, that is, for each of the components of the real environment, an abstract entity is constructed and communicated in the same way as the actual components to communicate among the abstract entities, the real environment is modeled.* (Figure 5, 8) (Taghizade, Vojdanzade, 2017, p.115)

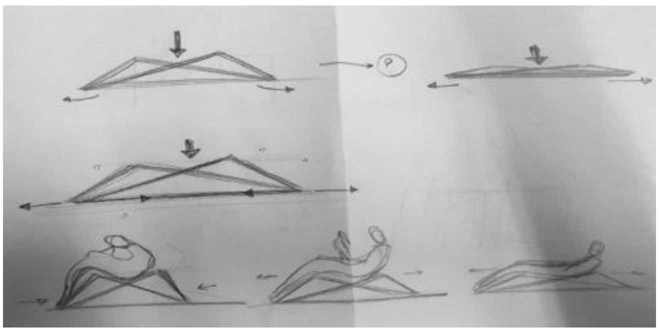


Figure 8: An Example of Structural Physical Model – Deployable and Transformable Chair, (Taghizade, Vojdanzade, 2017, p.115)

"What I hear, I forget; what I see, I remember and what I do I understand". This old Chinese quote may be well-known to us, and can explain the major need for Active Learning[6]. Active learning is a method of learning in which students are actively or experientially involved in the

6 - Active learning is a form of learning in which teaching strives to involve students in the learning process more directly than in other methods.

learning process and where there are different levels of active learning, depending on student involvement. (Bonwell & Eison 1991).

In this method, students must do more than just listen: They must read, write, discuss, or be engaged in solving problems. Also, active learning engages students in two aspects:

- Doing things
- Thinking about the things they are doing. (Renkl, Atkinson, Maier, & Staley, 2002)

Thus active learning has an important role in learning structure for architectural students.

Case Study Research Process –Teaching Structure with Structural Physical Model

According to the materials presented in the previous section, we chose the contemporary structures course at the postgraduate level of the University of Tehran to discuss.

This course talks about new structures and technologies in the contemporary world and is presented theoretically. It is worth mentioning that the postgraduate students studied different courses about structure and construction such as building, concrete and steel structures etc. in the bachelor's degree, so they have sufficient knowledge about structural behavior. But they did not use their theoretical data in real experience. At this educational level, post graduate level, they experience the same method to learn some concepts. But we presented the contemporary structure course, based on the purposed method and a practical section was added.

Deployable structure workshop

Students take part in a workshop during 8 hours and they learn basic concepts and scissors-like elements of geometry by perceiving and understanding the geometry of structures. According to suggested method of Problem Based Learning with Physical Model, we organized the workshop in two parts, theoretical and practical, to achieve our goals:

- Learning basic concept;
- Application of theoretical concepts to practical;
- Development of skills and knowledge by team work;
- The use of skills and gain experience;
- Motivation for continuous learning;
- Preparation to work in professional environments.

Theoretical

The first section, the theoretical part, is short and introduces the history of transformable structures, case studies in nature and man- made building from the past up to now and analyzes the geometry and mechanism of structural motion.

A large group of structures have the ability to transform themselves from a small, closed or stowed configuration to a much larger, open or deployed configuration. These are generally referred to as deployable structures though they might also be known as erectable, expandable, extendible, developable or unfurlable structures. (Jensen, 2004) But transformable is a comprehensive word to explain these structures.

Transformable structures could be classifed in different types. In this workshop we emphasized scissors-like element structures.

Advantage of scissors-like-structure:

- Retract and expand different times;
- Use all or part of its structure;
- Movement and transportation easily;
- Quick and easy installation;
- Possibility to use in crisis;
- Economical;
- Prefabricated;
- Light and compact;
- Install and disassemble by no specialist or equipment;
- Gathering, transmission and assemble different times.

Scissor units consist of two beams connected by a revolute joint in the middle section of the beam. This joint, scissor or intermediate hinge, allows the beam 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 beam 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 beams gives rise to three distinct unit types: translational, polar and angulated. (De Temmerman, 2014, Mira, 2010) As previously mentioned deployable scissors-like element structures, pantograph structures, categorize on three part:

- Translational;
- Polar;
- Angulated unit

Translational unit

Two straight identical bars or beams that form a translational unit join by intermediate hinge at the middle of the beams. In a translational unit, the unit lines are parallel and stay parallel during the deployment. By linking these units, a well-known lazy – tong mechanism[7] is formed (Figure 9). Translational unit classifies in two types:

- plane
- curve

7 - lazy-tong is a transformable single-degree-of-freedom mechanism.

The plane unit having identical beams is the simplest translational unit. The curved unit has non-identical length beams so two straight beams differing in length can form curved linkages. A plane or curve linkage is transformed from retracted configuration to deployed position by changing the deployment angle θ. (Figure 9, 10, 11)

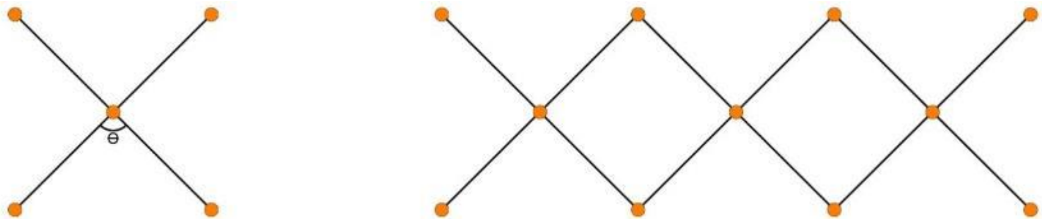


Figure 9: Plane Translational Unit and the Composed Lazy-Tong Scissors Mechanism

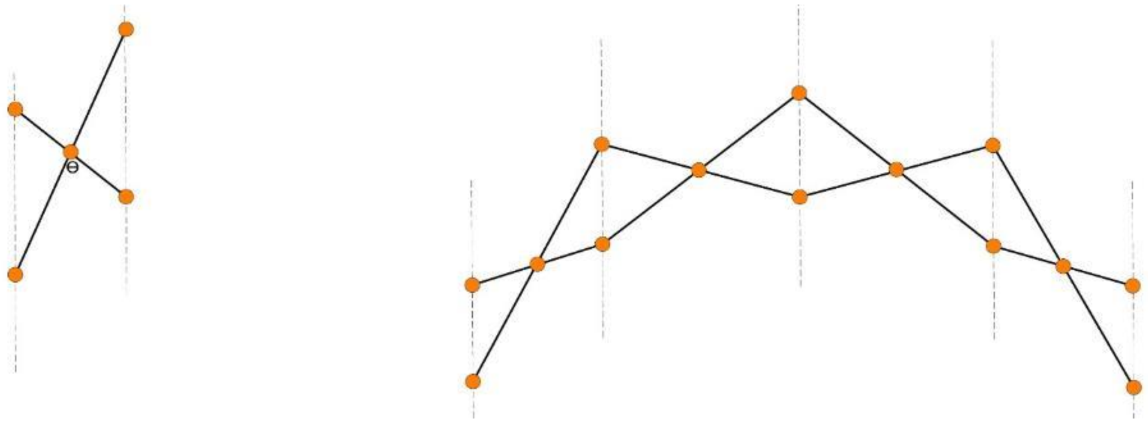


Figure 10: Curved Translational Unit and Linkage

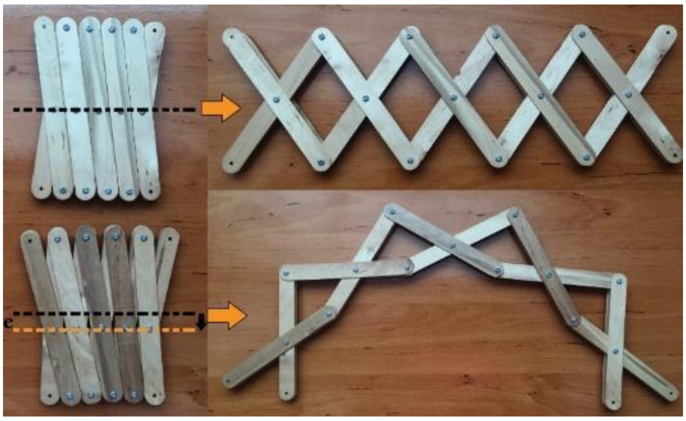


Figure 11: Influence of Hinge Displacement on the Shape.

Polar unit

Polar unit consists of two identical beams with intermediate hinge that moves away from the center of the beams to the end of them. The eccentricity e from midpoint generates curvature during deployment. The unit lines intersect at an angle γ. This angle varies strongly as the unit deploys and the intersection point moves closer to the unit as the curvature increases. (De Temmerman, 2007) (Figure 12)

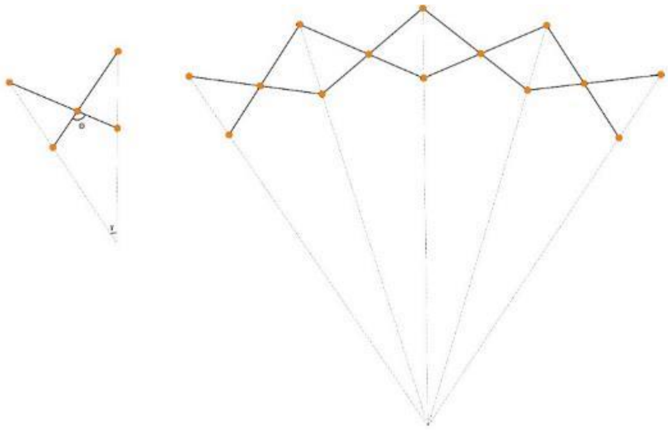


Figure 12: Polar Unit and Linkage in a Close and Open Deployment Position.

Angulated unit

A recent development in the design of scissor-like-structures has been the invention of angulated scissors by Chuck Huberman. A single angulated structure is made out of two symmetric bars hinged and kinked in the center. (Korkmaz, 2004). The major advantage is that, as opposed to polar units, angulated units subtend a constant angle γ during deployment for this to occur, the bar geometry has to be such that α= γ/2. This implies that angulated elements can be used for radially deploying closed loop structures, capable of retracting to their own perimeter, which is impossible to accomplish with translational or polar units, which demonstrate a linear deployment (De Temmerman, 2007). (Figure 13)

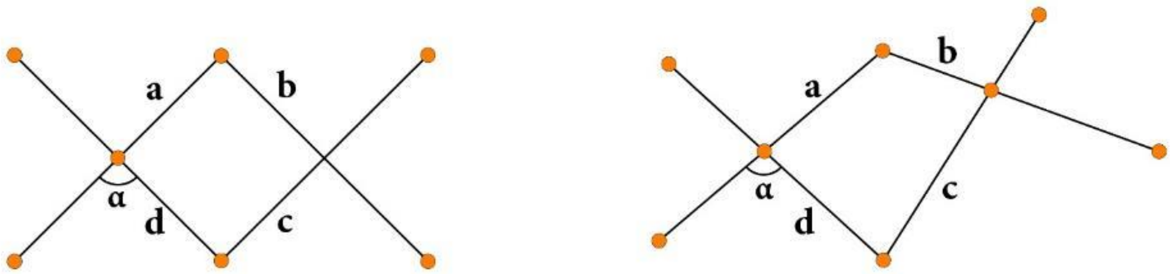


Figure 14: The Deployability Constraint

Deployability constraint

The design of this structure is difficult and complicated but the principle section of design is the deployability constraint. A formula was proposed by Felix Escrig which states that in order to be deployable, the sum of the semi-lengths a and b of a scissor unit has to be equal the sum of the semi-lengths c and d of the adjoining unit. According to the formula, the scissors linkage retracts concertedly into a compact bundle of beams. (Figure 14)

The deployability constraint is written as:

$$\mathbf{a + b = c + d}$$

According to the provided content, they learn the principle concept about scissors-like-structure. Now they know the advantages and disadvantages of them and why they need to use them.

Practical

Based on the subject matters in previous section and the project, students take part in a practical lasting 7 hours. Students make simple and complex physical models in different scales based on scissors-like-structure units with different materials in groups of 4 to 5 people. The selected materials, wooden sticks and straw in different sizes, resemble the main material for the final project in terms of structural behavior. Also students use variable joints for scissors-like-structures units which have been built by students for each material. They experience practically what they learned in the first part of the course.

At the same time the teacher sets a problem that concerns stability development and generalization of modules. Entire groups make an effort to solve problems as quickly and effectively as possible. (Figure 15, 16)

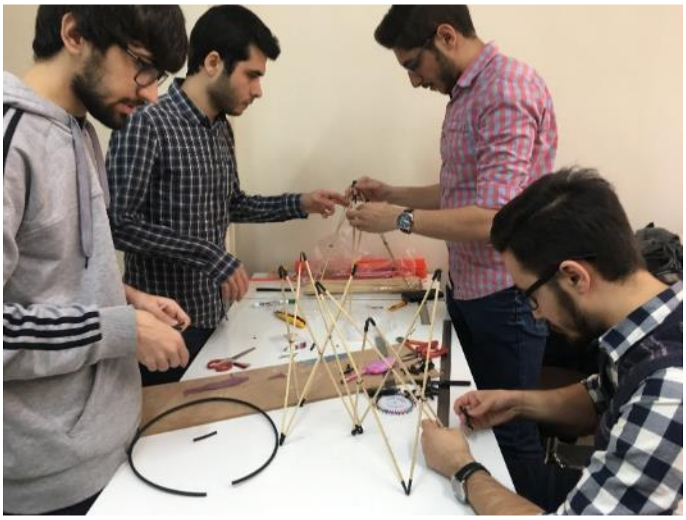


Figure15: Deployable Structure Workshop

Figure 16: Deployable Structure Workshop

At the same time as the modules were made, the students would also combine the models or change them to get new forms. The result of this process is the flourishing innovation and creativity of students. At the end of the workshop, the teacher sets a new project and asked students to design and construct a pavilion in real scale and an area of 10 square meters with deployable and portable ability with different materials that they learned in practical sections. It should be noted that there are many similarities between the materials that students use in the workshop and the materials that are considered for the final project[8].

Design and construction of final project

Initial design

After attending the workshop, students begin designing and presenting basic ideas and concepts in the form of sketching and etude models in three groups and within one month. They try to design a pavilion with retractable and portable ability based on what they learned in practical part of workshop. After numerous scrutinizes by teachers and according to various abilities of the proposed designs, design No.1 is selected. (Figure 17, 18, 19)

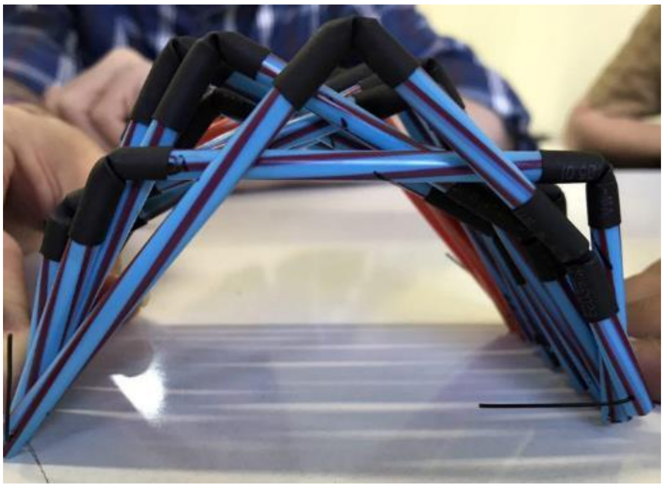


Figure 17: Design No.1

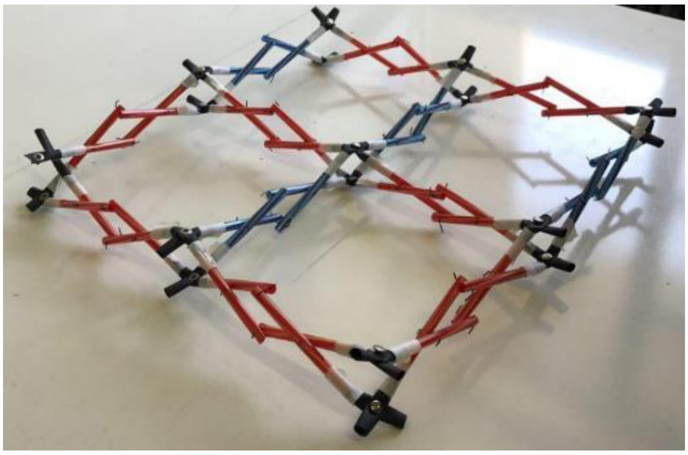


Figure 18: Design No.2

8 - In workshop, students made physical models with wooden sticks and straw, and in the final project, they should use low-density cardboard tubes.

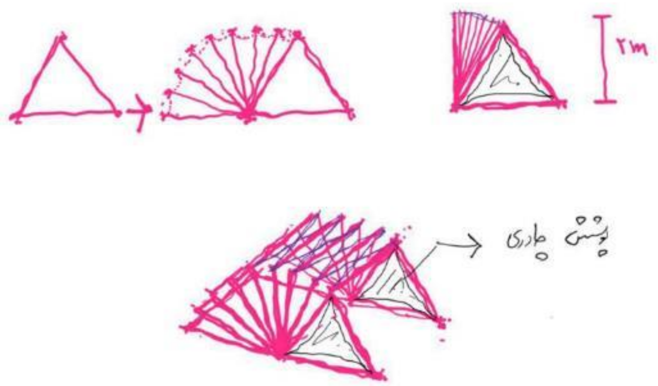


Figure 19: Design No.3

After selecting the project, students have to continue their work in a larger group (19 people). Accurate and regular planning and coordination between the entire group is very important to present a successful project. (One of the most important goals in the selected method) They must continue to design and fix the defects. After that, they are going to build it in real scale.

Final design and construction of the project

Students work on design No.1 and they face different challenges. For example, they had to design different joints to open and close their Pavilion. So students learned how to build three connections and joints that were needed for the final project. (Table 1, Figures 20, 21 & 22)

Table 1: Connection Types

Connection Type	Description
Primary or End Connection	The two elements are connected to each other so that they can be stayed at different angles from zero to 360 degrees.
Intermediate Connection Type 1	The two elements are connected in a place other than the beginning and the end.
Intermediate Connection Type 2	Connecting more than two elements to each other

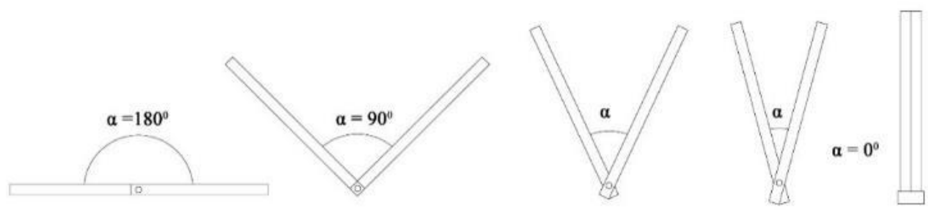


Figure 20: Primary or End Connection

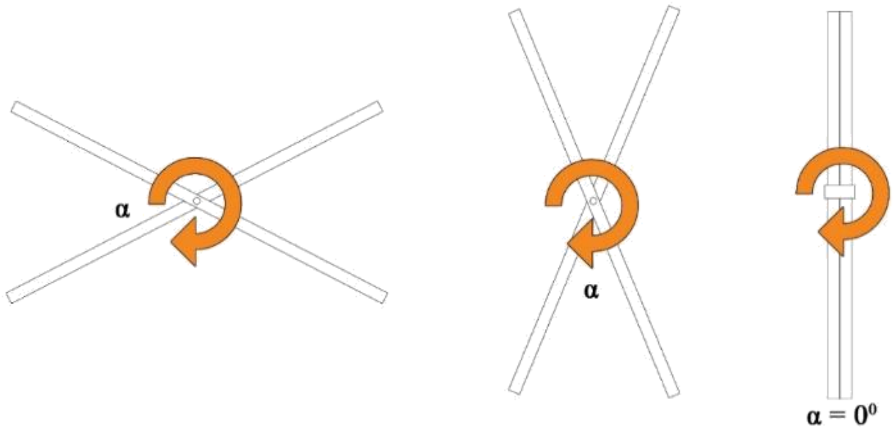


Figure 21: Intermediate Connection Type 1

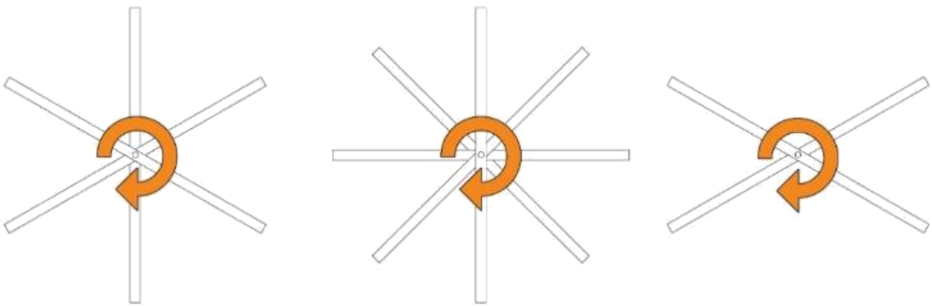
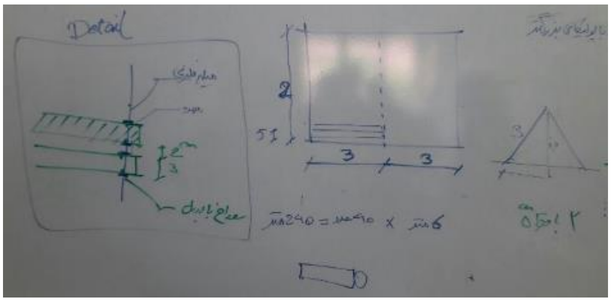


Figure 22: Intermediate Connection Type 2

The primitive design was built in small scale and when they wanted to build it in real scale based on specified requirements, they were confronted with different challenges such as structural instability and buckling and bending of structural elements because of long and slender elements[9]. In designing and building joints the students were not allowed to use any pre-fabricated or cast elements.

In the initial design, the pavilion transformed with difficulty and it needed high occupancy level for opening and closing. (It opened and closed in one axis). Figures 23, 24, 25 Illustrate design, modify and optimize process completely.

9 - Materials include cardboard tubes with a maximum diameter of 4 cm, screws up to a diameter of 4 mm, a U.P.V.C pipe for joints, cable for controlling the opening and structural stability.



Figures 23, 24, 25: Design and Construction Process

- First step: using two different frequent alternating patterns for visual legibility. This design could not retract and deploy in two axes and there are no braces. (Figure 26)

Figure 26: First Step: Using Two Different Frequent Alternating Patterns for Visual Legibility

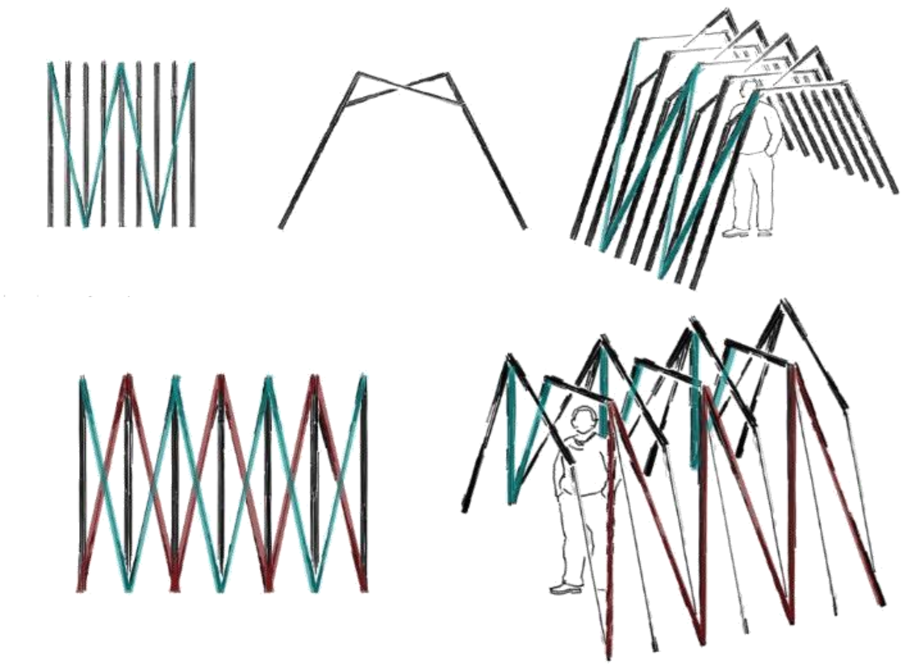


Figure 27, 28: Second Step: Using V-Bracing in Both Side of Pavilion for Lateral Stability and Retract and Deploy in Horizontal Axis.

- Second step: using v-bracing in both sides of pavilion for lateral stability and retract and deploy in horizontal axis. (Figure 27, 28)
- Third step: eliminate additional components and complicated connections to have a simple design and pavilion. (Figure 29, 30)

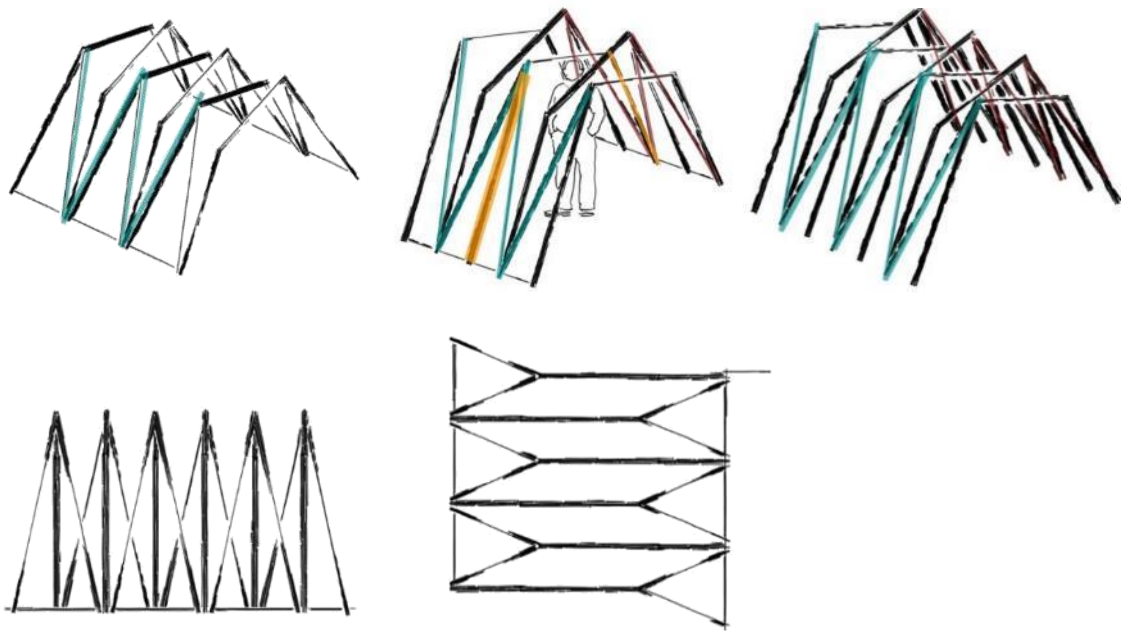


Figure 29, 30: Third Step: Eliminate Additional Components and Complicated Connection to Have a Simple Design and Pavilion.

Finally, they find a solution based on their knowledge about static and structural courses through numerous discussion with each other. The proper approach is to use braces. They were able to adjust the length and number of members by using the braces, as well as the possibility of opening and closing in two directions. In this case the pavilion covers more area.

After designing the projects students build a full-scale modular of the structure (scissors like element structure) with low-density cardboard tubes, bolts and U.P.V.C pipe for joints.
Using low- density tubes caused many problems during construction. (They have to use low-density tubes) Low- density tube with low cross section is like a long column. They had to prevent long column from buckling. Using cable and lateral bracing is a good solution to stable the pavilion and prevent it from lateral force.

This pavilion could develop in 2 orientations easily and could be used as different functions such as pavilion, exhibition, gazebo and temporary shelter. The full- scale structure – pavilion- is the final outcome of our purposed method. It shows students attempts, team working and perception of structural behavior.

Conclusion

There are variety approaches in teaching structure to architectural students. The overarching method that we used for the structural course in University of Tehran is Problem Based Learning with Physical model. Using Problem Based Learning, students could present very good team work during designing to construction. They encountered several challenges, but they were able to provide the appropriate solution and achieve specific goals of Problem Based Learning by scheduling.

The most important goal of this method is that students use their knowledge in the future in professional environment.

This is done through the following:

- Regular knowledge learning
- Development of critical reasoning skills
- Obtaining self- command skills for knowledge search
- Creating motivation for continuous learning
- Developing knowledge and skills for team work (communicative skills)

Using physical model in teaching structure for architectural faculty has many advantages. These models let them explain the structural behavior of a mechanism. They experience different tensions that learned before.

In addition, using Structural Physical Models on various scales contributes greatly in design and construction processes. In this method, students achieve understanding of structure systems, load path and loading by using different structural models without the need for complex numerical calculations, and they realize what is going on in a structure and how forces transfer and what happens in structure?

It is obvious that physical model has a main role in this learning process which implies that students will learn about structural behavior during the process of making physical models. In this situation the materials used to make the models are key factors of the method. (As we tried to use similar material in workshop and full-scale structure.) Making physical models is an intelligent and effective way to visualize and study the fundamentals of the structural behavior. At the end of term students build a full- scale structure. The full-scale structure gives students a good chance to examine their studies and research. They face different challenges that are different from what they did before in the workshop.

The use of these two methods together promote students' abilities and skills. Also, the final product shows that Problem Based Learning along with Structural Physical Model have a significant impact on learning about structures and it prepares students for the professional world. In other words, learning is the natural result of doing.

The main aim of this project was to find a new and innovative solution to encourage architectural students to learn structural courses easily and perceive structural behavior without using complicated mathematic calculations. Also in this method they were involved in an active learning environment. They gained different experience during design and construction processes, such as the development of team – working and communications skills. Also they constructed their own structure for the first time.

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