"Experimental Workshop in Unconventional Structures: Deployable & Tree-Like Structures SMiA - Training and Research at Barcelona Tech"

Omar Fabrisio AVELLANEDA[a] - Natalia Paola TORRES[a] - Diana PEÑA[b] - Ramon SASTRE[c]

[a] Phd Student - Polytechnic University of Catalonia, BarcelonaTech, Barcelona, Spain

[b] Phd Researcher - Polytechnic University of Catalonia, BarcelonaTech, Barcelona, Spain

[c] Professor Dr.-Arch. in Architectural Technology at the Dept. Construccions Arquitectòniques I- ETSAV BarcelonaTech, Barcelona, Spain.

http://smia-experimental.com - smia.experimental@gmail.com

Abstract

The purpose of this paper is to share the experience, training and teaching students in non conventional structures area. The research group SMiA Structural Morphology in Architecture performed a practical and theoretical workshop designed to learn unconventional structures in architecture. The main objective was to propose a practical teaching method, the students gain the necessary tools to design lightweight and membrane structures developing an architectural project. Physical and digital tools are utilized, including WinTess3, Sketch Up, Grasshopper, a parametric-geometry-development-and-testing software.
Lightweight Construction Course is an elective architecture program at ETSAV School of Architecture of "El Vallès", leading by Professor Dr.-Arch. Ramon Sastre. The main topics that were developed are: Deployable, Tree-Like, Reciprocal Frame, and Tensegrity Structures. In the present article we explain the practical experience in Deployable and Tree-like Structures. The course was offered to students in the last year of career at UPC, international students (Erasmus) and Master students.

Keywords: training, theoretical, practical, unconventional, deployable and tree-like structures.

1. Introduction

SMiA believes in an educational program that involves lots of hands-on experience. It is through activities such as laboratory and in-company work where students can learn and develop the skills they need to meet the challenges and demands of tomorrow's work place. (Peña [1])

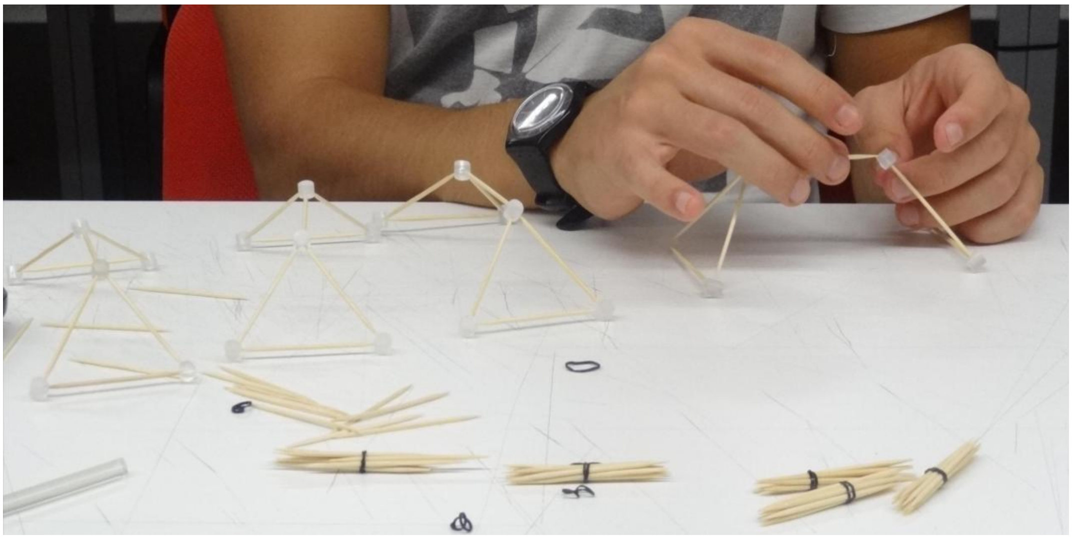


Figure 1: Learn by Doing - Workshop SMiA UPC Polytechnic University of Catalonia.

¿WHY LIGHTWEIGHT STRUCTURES?

- Lightweight structures have many benefits especially relative to their weight and cost.
- Can be used to cover large open areas.
- It is possible to observe their load-deformation behavior.
- Structural stability is partially dependent on the membrane pretension.
- Can be assembled quickly, saving on-site labor and time.
- Easily transportable.
- Can be designed to be either temporary or permanent.
- Can be quickly assembled and disassembled.
- Can be quickly removed and then reused later.

2. Objectives

2.1. General Objectives

The main objective is introduce students to the conceptual and practical world of lightweight structures with the end goal of having the students develop their own lightweight-structural model that solves a real-world problem. They will gain an understanding of the behaviors of these complex structures using both physical models and software.

Comprehensive introduction to the subject of tensioned buildings, deployable structures, tensegrity, reciprocal and tree-form structures and enable students to develop an architectural proposal for a small tensed covering such as a tent, shade, or pavilion, etc.

2.2. Specific Objectives

By the end of the course, students should be able to:

1. Explain the basic unconventional-structure geometric typologies: Deployable, Tree-Like, Tensegrity, and Reciprocal.
2. Use formfinding to develop new free-form structures.
3. Modeling and prototyping using high-quality, sustainable, recyclable, and inexpensive materials.
4. Define and/or develop materials, construction details, fabrication requirements, and assembly processes.
5. Through physical and digital models, evaluate kinematic behaviors and understand their impact on design.
6. Utilize iterative feedback processes between physical modeling and digital simulation to develop possible applications and uses.

3. Methodology

The idea is to apply **didactic strategies for comprehension and learning of design and structural concepts**. Two different modes of application are implemented in classroom sessions and in structures workshop: First. a **Theoretical class** and Second. a **Practical class.**

In the first the teacher explains adequately the theoretical principles by means of didactic models. This kind of practice allows the students of architecture to realize in better ways the possibilities of use and application of the different structural typologies. In the same sense, the possibility of observation of structural work of their own architectural designs, allows future professionals to achieve a better conception of the structural solutions that affect positively their designs.

The course began with an exploration of geometric solids and the relationship between them, such as with modules, repetitions, groupings, dualities, truncations, and subdivisions.

The course then continues into four topical areas, while alternating between the following:

- First, a review of basic theoretical concepts, morphology, and geometry for each system. During this stage, students explore concepts and grow their understanding of these complex systems through trial-and-error, hands-on rapid prototyping using low-cost, easy-to-work-with materials such as paper, plastic, and wood.

- Second, more advanced, digital-tool-based process where students are able to explore possible configurations for each of the structural systems. Goals include, understanding stresses and forces, how the system will be closed, defining constructive details, development of membranes, and assembling the structure.

By the end of the course, students have developed, analyzed, and built a project based on the theoretical concepts learned in the classroom as well as the practical issues encountered while hand-building models.
The SMiA-led workshop was a valuable, continuous-learning opportunity for students faculty alike. Participating with students while they explore and create lightweight structures reinforces our motivation to continue our lightweight-structures work.

3.1. Theoretical class

In this case the tool is a power point, and the class is define by the follow points:

Topic
Definition
Precedents
Another Researchers
Samples
Personal Experiences
Classification
Geometry
Formfinding
Structural Analysis
Case of Study
Application
Future Research

To keep students interested during the remainder the lecturer
- use relevant and current examples to illustrate the point;
- where possible draw on the students' experiences;
- use rhetorical questions to encourage students to keep on track;
- change the demands on the student as the lecture progresses. Vary between note taking, listening, and active participation ;
- use visual materials or arte-facts that are relevant to the topic of the lecture;
- use live links to the web to demonstrate currency of the material being presented;
- try to use maximum 45 minutes in the theorical part, or is more time, take a break to refresh the mind.

Example
Links with solids lecture class, a basic example:
https://docs.google.com/file/d/0B_4Ta4Tfl4bFcUwzcDRvOFQwaWM/edit
http://smia-experimental.com/2013/10/15/workshop-2013-ii/

3.2. Practical class

After the student understood the theoretical class it is necessary realize a practical exercise to reinforce the concepts and be clear with the complex material.

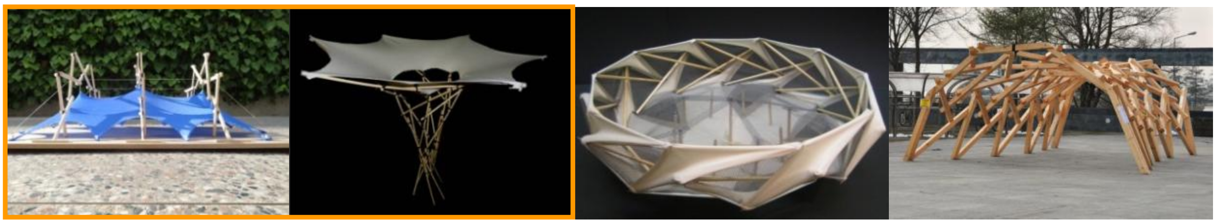
Hands-on Tasks
All exercises should be straight-forward and clear so students understand what will be learned and why. The instructor provides a base for student learning such that students can then, after learning basic geometric units, create new generate new groupings and variations through repetition. This is why the foundation of the first workshop is a solid's class. This serves as the basis for more complex structures such as deployable, tree-like, tensegrity, and reciprocal structures.
Model-Building Materials. Balsa-wood/cedar bars, adhesives, thread/string/cable, paper, scissors, fabric (including lycra), pins, and so on. Recyclable Materials and Personal computer.

Example
Links with tree-like structures & deployable practical class:
http://smia-experimental.com/2013/11/21/w-shop-13-ii-reciprocal-structure-tree-like-structures/
http://smia-experimental.com/2013/11/06/w-shop-13-ii-deployable-structures/

We introduce with our lecture class in Lightweight structures four workshops.
The general class divides en 10 topics and 4 workshops which it is possible to impart for a big and small group.

Topics

1. Introduction
2. Cables
3. Membranes
4. Simple forms & **Solids** (workshop)
5. Air supported & pneumatic structures
6. Domes & **Tensegrity** (workshop)
7. **Deployable structures** (workshop)
8. Reciprocal & **Tree-form structures** (workshop)
9. Structural analysis
10. Patterning
11. Details
12. Erection + Pathology



a. Deployable b. Tree-Like Structures c. Tensegrity d. Reciprocal Structures

Figure 2: Lightweight Structures & Unconventional Structures.

4. Evaluation Criteria

To objectively assess students achievement, the following is taken into account:

- Active participation in both the classroom and lab.
- Application of creativity as well as skills learned to the systems studied including how they are applied to the final project.
- Construction of all physical models.
- Development of digital models using WinTess.
- Final project results.

During the final class, a survey is given to solicit student feedback including: student interest in what was learned, whether they enjoyed the class, and if they feel it contributes in a positive way to their knowledge. This information is used to improve future courses.

5. Practice & Results

Figure 3: Practical experience with the students.

5.1. Tree-Like-Structure Practice

Objective

Explore tree-like-structure configuration elements, their classification and assembly methods.
Develop and test the application of tree-like structure through formfinding and computer software.

Concept
Tree-form architecture is based on natural forms such as where a tree's foliage serves as the roof. The branches and trunk are the support structure.
The basic concept was took from the nature, for example Umbela flower and applied in important architectonic projects. (Mauri [2])

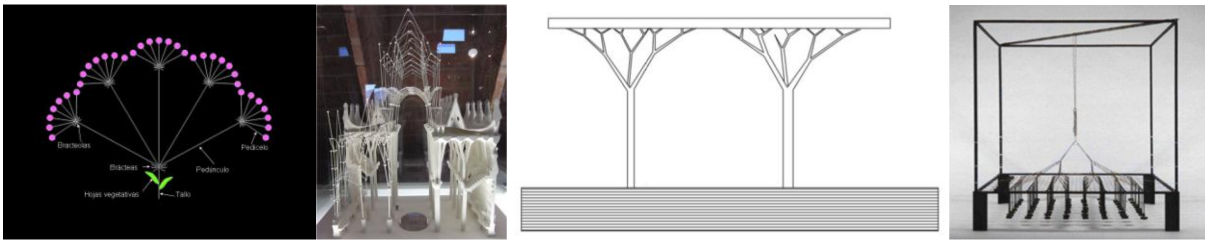


Figure 4: a. Umbela flower - b. Sagrada Familia Gaudi (Barcelona) c. Design sketches and model by Frei Otto (Stuttgart).

Tree-Like Structures name defined by Frei Otto. The German architect and scientist spent his entire life studying the form-finding processes of nature.

Examples Students - Class Exercises
Students performed and achieved the objectives successfully . They gained an understanding of the behaviors of these complex structures using both physical models and software.

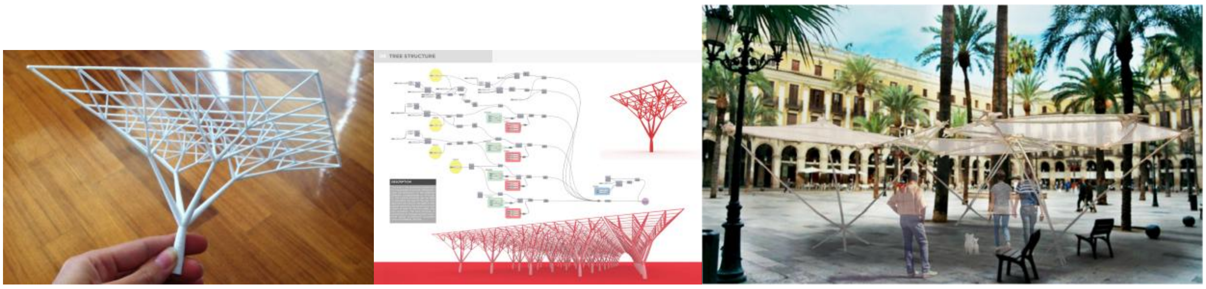


Figure 5: Physical model and digital model - Students results.

5.2. Workshop deployable structures

Introduction
The deployable structures study and application is becoming more popular, new architectural applications are required for adaptive structures, that can satisfy the current needs of change and adaptability.
Today there are a variety of proposals and geometric scale models that have promoted these structures as an alternative flexible, lightweight and transformable.
SMiA aims to involve academia understanding of deployable structures through experimental workshop to generate new approaches to architectural design beyond the traditional static architecture.
The workshop aims and deployable structures, introduce students to the transformable architecture, promoting alternative design from folding structures that generate constructive advantages:

- The lightness
- Modulation elements
- The easy assemble
- The structural efficiency
- And the ability to be portable.

Objective

The workshop purpose is the students to explore the different types of deployment and spatial configurations that can be achieved from the study of the basic unit of scissors.

Understanding through scale models the complexity of geometric design, construction, connections, mechanisms of this type of structures, that require interdisciplinary research. So, the student proposed constructible designs that approach the construction detail and assembly process approach.

Also learn about the different design tools and use of materials in real projects involving structural mobility.

Methodology

The methodology proposed by SMiA to expose and explain the issue of Deployable Structures students, develops in two parts.

The first part is the description of the theoretical principles developed works, recent research and new design approaches from the deployable structures.

The theoretical explanation is complemented by the exhibition of scale models, that is to say, the student understands from the outset, through real models, the deployable structures topic; the main features of the structure and the potential space that can be achieved with this structures.

Figure 6: Scale models exhibition in start class.

The Content developed in the first part of the workshop began with the comparison of deployable structures and morphology in nature, analyzing the different change strategies so that nature uses in specific defense needs, reproduction or adaptation to their environment.

Thus, the different deployable structures applications have evolved over time, and are based on the nature inspiration, and within the architectural design is a practice that mankind has developed since its inception. The nomad tribes erecting shelters built with alternative folding lightweight materials, and shaped to facilitate transport, besides designing different household items that use the pliability to meet a need. (folding chair, umbrella).

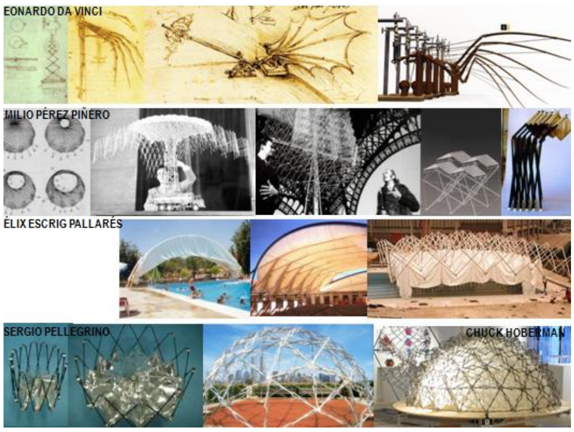


Figure 7: Deployable nature. Armadillo, sensitive plant and peacock.
Figure 8: Pioneers designers in deployable structures evolution.

The discovery of new materials to build, together with advances in mechanics technology allowed such structures were developed on a large scale, from ancient times to the present day. Students know the evolution of deployable structures through the description of the projects by leading designers and researchers as: Leonardo Da Vinci, Barde Salden Watkins, Richard Buckminster Fuller, Emilio Pérez Piñero, Frei Otto, Albert Moore , Theodore Zeigler, Santiago Calatrava, Carlos Henrique Hernández, Felix Escrig Pallares , José Sánchez Sánchez, y Chuck Hoberman. Which have provided the theoretical basis through their projects and patents, which allow further explore these structures. (Torres [3])

Also, SMiA emphasizes in new digital tools. Describing the use of new technologies, parametric design and digital fabrication, which apply to the deployable structures design, to explore new geometries in convertible spaces.

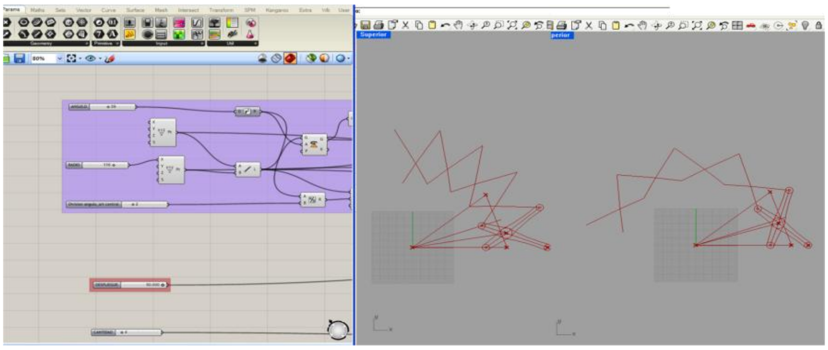


Figure 9: Parametric grouping definition - Eccentric scissors.

The workshop presents systems deployable structures grouped in three main themes:
1- System type **scissors**. 2- Convertible roofs or **retractable** membranes. 3- **Mixed** systems.

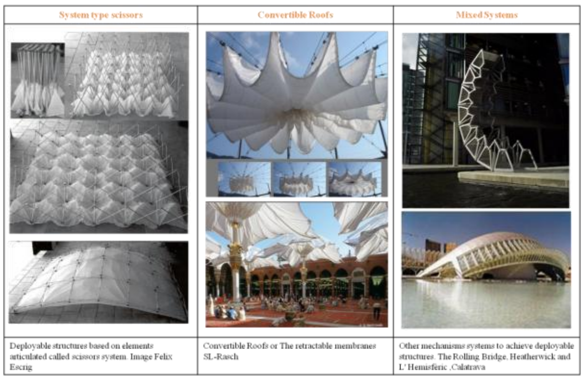


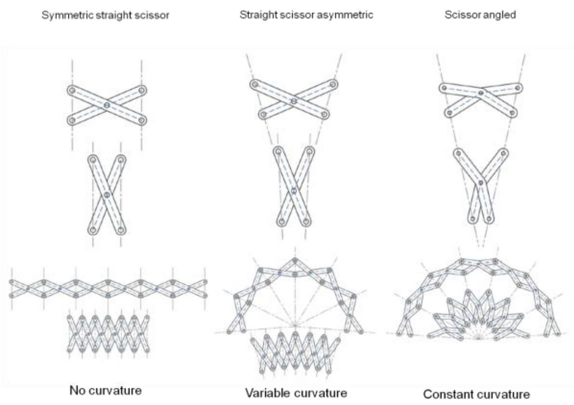
Figure 10: Various Deployable Systems.

Because the workshop is for a short course, only deepens the scissor system, with the intention that students understand the concept of the basic unit of scissors, and from there to make the practice through the exploration of variations and complex group, to form deployable space assemblies.

The Practice
System is defined as articulation, is the joint between two elements or rigid bars. Some designs have been replaced by other elements such as bars panels.
From the scissors basic units group, is possible to achieved a spatial grouping or deployable linear group. Geometric and spatial features defined by the central joint location and end joints.

Scissor systems classification by joint location, which generate the different deployable types.

Once you understand the scissor system concept and the basic unit, it is necessary to submit a practical exercise that describes the different possibilities of groupings and variations, depending on the joints is location. The student must make a scale model to the interpretation of the basic concept and a proposal for a geometric variation.



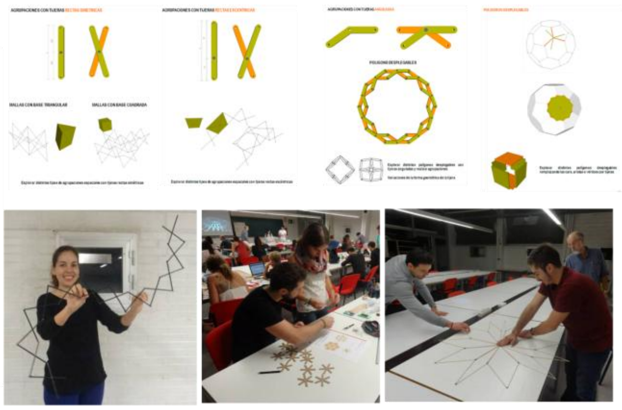


Figure 11: Scissor classification system - Deployment Types. www.hoberman.com
Figure 12: Scale models exercises - Deployable structure.

Conclusions

This study concludes:

- Following the methodology proposed different concepts are understood, including the scissors basic unit concept, the different grouping and variations, which is possible to assemble a stable deployable structure system.
- The students understand through the scale model performance, the movement and the geometry, and how the element geometry affects directly the deployment type that they want to accomplish.
- The model development leads students to think about the connections and construction details, to simulate a real project construction and its assembly.

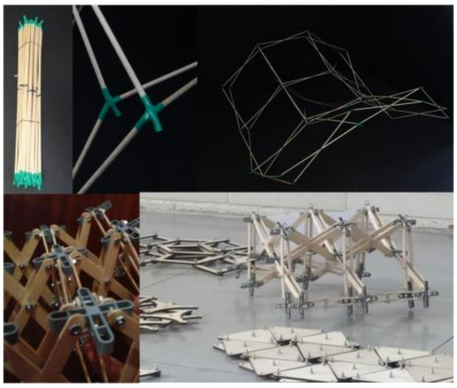


Figure 13: Connections design in models.

Figure 14: Scale model - deployable arch.

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