The paper describes an architectural design studio for the students of 4th year of studies in the Aristotle University of Thessaloniki. It has been done since now as a workshop, where models of lightweight constructions are done with the presence of the tutors. The results are till now promising and erase certain educational issues and goals.

Introduction
The course “Nature & Space Structures” is an architectural studio for the 4th year of studies in Aristotle University of Thessaloniki. It started 23 years ago and it still goes strong due to the fact that the students construct architectural models of lightweight materials in the studio. Such design experiments usually employ elastic fabric for the construction of tents. Based on the precedent of Frei Otto’s studies with soap bubbles for modeling inflatables, we introduced balloons, alongside other constructions such as metal skeleton models, trees structures etc. Due to the largest student audiences, the course invited more instructors that contribute in this paper, two of them from other schools of architecture in Greece, where joint workshops were
organized. The course includes the following thematic areas:

- nature as a source of inspiration in the design and construction of space constructions, biomimetics,
- the 4 basic solids in the tensile membranes, with double curvature surfaces (‘curved’ cylinder, ‘curved’ cone, ‘saddle’ and hyperbolic paraboloid) and the construction of paper models,
- aesthetics as a constructive concept result or architectural form following static function,
- hanging constructions, suspended roofs or ceilings/buildings/membranes, in analogy to suspended bridges where pillars stand higher than the roofs and are supported by cables,
- the trees as a source of inspiration for building elements such as columns or structures,
- wireframe surfaces or wireframe constructions, space frames, rod and cable systems, tensegrity systems, cable surfaces,
- tensile, retractable, self-supporting membranes with double curvature surfaces,
- model drawings and pattern designs using rhino and grasshopper software,
- inflatable structures using balloons for air-halls, tubes for air-tubes and air-cushions.

**Educational Objectives**

The core idea is the implementation of the 5 word mantra to the curriculum of schools of architecture that are: society, environment, cost, technology and research. The main educational objectives of the course “Nature & Space Structures” are:

- **Familiarity with curves**
  Double-curvature surfaces in the membranes contribute to their resistance to wind turbulence increasing their stability. Familiarity with curves relates to the criterion of strength of light materials and the corresponding form of the membranes, which are in their majority paraboloid and ellipsoid solid shapes. 
  The use of "elastic" materials for the fabrication of membranes such as lycra, tights, rubber, balloons, etc. contributes to the form-finding of double curvature structural surfaces which are anticlastic (tensile), or synclastic (inflatable).

![fig.01 - Apostolis Apostolinas, Georgia Kissa, Periklis Kyriakidis, 2010. Small shed for sun and rain protection, appropriate for a bus stop. Double layered membranes with arches and pillars show self supported construction. Embedded columns without joints, doesn’t satisfy lightweight construction logic. It can be named, ‘pole dancing’ tent](image-url)
Educational objectives from an Architectural studio on Nature & Space Structures

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Design from outside to inside

The ‘shell’ architecture where appearance is prioritized, is applied to limited examples of small internal complexity (few uses in the building program), or for special designs such as landmarks or stadiums or airport buildings. In no case has ‘shell’ priority been applied to buildings with great complexity of spaces and uses. Usually, we start from indoor functions to form a building plan. The design process for tensile membranes is considered unconventional since it is primarily concerned with the external surface configuration and secondarily with the interior design. Nevertheless, the shape of the outer shell results from the static function.

**Drawings after the model**

When designing tensile membranes, first we construct the model (a form-finding procedure), and then we do the drawings by measuring dimensions from the model! This is because rubber fabrics are used in mock-ups. By stretching the fabric, the shape of the surface changes, so the depth of the arches decreases (umbrella) or changes the height of the posts.

In early days, designers used to apply glue in the fabric of the model in order to neutralize the elasticity, so it could be cut into small pieces that were the cutting patterns on scale. From small (model) to large (real scale), they scratched the patterns with the use of a pantograph. This was the process before the emergence of computers.

**Membrane drawings with pc**

The model drawings and the pattern designs are made using a 3D software such as Rhino with
parametric design plugin grasshopper. Special software calculates loads, wind pressure, cross sections of poles, cables and membrane types. In the implementation drawings, one of the most important issues is the design of the membrane patterns (membrane construction drawings) resulting either from the modeling or from a design in a computer application.

The ‘dynamic’ model is more than a 3D object

The forces applied on the model drive the designer into a statically sound construction as on a real scale! The membranes can be torn, the balloons can be broken, the poles bent, etc. The architectural form derives from static function.

An important issue is the use of pillars that are anchored by cables to the ground. If the posts are embedded in the ground, then the lateral forces bent them, whereas if they are not embedded, the forces penetrate vertically along the pillars, resulting in better buckling.

Retractable membranes, in-de-flate, joints - movable constructions

All lightweight roofs that are built for protection against sunlight or rain must have a mechanism to close at night or winter for their own protection. Thus, a membrane should be able to gather for protection from rain, deflate for storage, move to follow the sun, etc.

In order to achieve multi-functionality, all sorts of mechanisms are useful like scissors mechanism,

fig.04 - Kyriakos Kyriakopoulos, Dimitris Siokis, 2012. When open, the tent becomes tensed, without folds or rinkles

fig.05 - Penelope Papadimitraki, Nikoleta Sidiropoulou, Fotis Chatzichristakis, 2012. The foldable shed can fold and unfold, can change height and can change its angle! All these functions can be done using very simple mechanisms

fig.06 - Tania Lazoudi, Efmorphia, Tzakopoulou, Ellie Vlachou, 2012. The use of used materials to cover a metal skeleton canopy has its own values
umbrella mechanism, or elements that move, pull, open, rotate, etc. Smart ideas may find inspiration in kinetic art or multi-purpose everyday life objects. Hooks at the edges of the membrane span the arcs of the structure and stretch or glue the membrane. Wires that are sewed in the fabric perimeter also improve strength. Rings that are sewed on the fabric and run in a wire-guide can facilitate the retraction or extraction of the membrane.

**Ephemeral architecture**
The need for creation is beyond the time-lag and low lifespan of architecture. The relationship between human life and its creations is of great interest. In inflatable constructions, the balloons from the models are deflated before they are photographed! An example of traditional ephemeral architecture is the Yurt tent of Mongols as many other tents from people who live as nomads. The materials used for membranes have a certain life span depending on the quality from 5 years to 20. Ephemerality as a concept is crucial in architectural education. Nothing will last forever and the sooner we realize it the better, this will enable us to consider ephemeral architecture as important as a monument. Because of the variety and differences in shapes and materials, sometimes ephemeral structures can give us the same content or fulfillment as in designing heavy buildings. All these years, very often the students wouldn’t want to leave the room after they finished the model.

**Recycling light materials**
Most of the light materials currently used in the construction of buildings are mainly recyclable. Generally, as the years go by, the lighter the constructions are made by saving raw materials, protecting the environment. The fabrics and metal parts of the tents are usually recyclable.

**Shell as a result of atmospheric pressure and under pressure**
A sea mattress is inflated and acquires static properties. Layer tubes are transformed from flexible plastic into a static element due to pressure.
Air halls, air pillows and air tubes, are the usual forms of inflatable structures made by inducing air pressure inside the cavity that is higher than the atmospheric pressure. Soap bubbles are used as a tool to find shapes and because of their instant appearance they are photographed for further study.

Wire-frame constructions
With technological evolution, buildings are slowly becoming lighter than the previous ones. It is said that when the ratio of movable weights in relation to own building weights approached the unit, it was then when the need for static calculations and ‘structural’ engineers emerged. Thus, the passage from the whole-body construction to a vector construction or space-frame construction or from the

Egyptian pyramids to the pyramid of the Louvre was made. In the grids-wire frames, vector active skeletons, their first property is that they act statically as a whole so that if a beam is under any kind of force, then all the beams react to the pressure.

Guyed Structures - floors
Aguyed structure may be a space frame or a ‘high technology’ cable and rod system or a tensegrity system! It is recognizable in the form of suspended bridges where the roadway is suspended by cables that are connected to pylons much higher than the road surface. At the site of the pavement, we introduce the roof of the building and the pillars become columns. From the top of the columns, wires are tight and support the roof or ceiling.

To understand how the static function is achieved, we consider the bars as compressive elements and the cables as tensile elements. In the first
spaceframe skeletons, all the connections were rods. The spatial lattice is based on the equilibrium of compressive and tensile forces.

**The tree as form of building static element**
A typical example of skeleton is the tree trunk with its branches and twigs which under the ground is roughly the same as its roots. The cross section of branches and roots is reduced towards the edges. The durability of the large trunk is as strong as all the twigs together. The distribution of forces begins from the twigs to the branches to the trunk towards the roots. The shape of the tree as a static element (as a column) is of great interest both from an aesthetic point of view and from a biomimetic standpoint, as a basic imitation of nature. The shape of trees is found in nature in the form of nerve systems, lightnings, kidneys, the flow of water from mountain tops to valleys, the river deltas, the leaves, etc.

![fig.10 - Coffee bar in ‘Papanikolaou’ Hospital, Thessaloniki, 2003, arch. Nikos Tsinikas & Fani Vavili. Every tree has one column, 4 branches and 4 twigs in every branch. 16 twigs, support a flat wire-mesh equally. After the height of doors, there is are vertical surfaces but foldings](image)

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**The laboratory**
The objective of the laboratory is to build models of small lightweight constructions. The course starts with a presentation of the content of the exercises and adopts a hands-on approach, with students constructing models in the presence of the tutors who solve questions and inspire for the realization. The mockups are plotted on plans or designed on the computer and photographed. During the workshop, the models are: a) double curvature paper constructions of the 4 basic shapes, b) a tensile membrane, or a folding-retractable membrane, or a self-supporting membrane, c) a suspended roof structure, or a tree as skeleton, or a

![fig.11 - Antigoni Drosouni, Fabiana Maria Ibanez Medina, Nikos Konstantinidis, 2017. The hyperbolic paraboloid, as a result of a curved cylinder. Paper double curvature constructions. By cutting the cylinder in half, we get a ‘curved’ truncated cone or a ‘saddle’. By removing the 4 triangles from the ‘saddle’, we get an hyperbolic paraboloid. All forms are part of the curved cylinder. If we consider the ‘curved’ stripes of the cylinder as being the patterns, then we can construct a double curvature surface by glue them together](image)
grid-wire surface structure and d) an inflatable structure or a collapsible - folding structure. The light weight construction models may respond to a diversified program, ranging from: open-air market, open-air canteen, open-air exhibition, light canopy of small stadium or swimming pool or parking, art warehouse, car roof, kiosk refreshment space, shelter, shed, portable concert hall, etc. Architectures or building elements may be inspired, refer to, remind, or imitate forms and structures of nature and biology.

The materials used for the workshops are:
- small rigid base (wood, chipboard, thick insulating sheet, thick cardboard),
- for the membranes: elastic-swimsuit or lycra, linen fabric, tights, net, threads, twine, fishing line,
- for double-curvature surfaces: paper or cardboard in different shades to show the cutting pattern,
- for inflatable structures: large balloons for air-halls, many small balloons for airtight cushions, cylindrical balloons or plastic transparent or opaque tubes (electric wire spaghetti, plastic small tubes) for air tubes,
- for wire mesh constructions: wires, threads, string, cord, mesh, nets, metal sheets, metal, metallic cables, plastic, paper tubes, reeds, bamboo,
- for support and anchoring: strong wooden sticks, matches, wire, glues, staples, fasteners, pins, metal, metallic cables, plastic, paper tubes, bamboo etc.
- necessary tools: scissors, stapler, hammer, pliers, etc.

For every constructed model, a meaningful site is to be chosen for its positioning or the opposite way, the place is pre-decided and a lightweight construction is...
designed to be built. Light constructions are not in “competition” with heavy buildings, they rather coexist. As an example it is reported that in the Parthenon conservation works a tensile membrane was set up inside the monument. Using the logic of the landmarks, the counterpoint between a curved structure and a geometric building, allows for their coexistence.

Outro
The course on lightweight structures is one of the best examples for architects to understand forces of tension and compression thus static function. It motivates students to design curved surfaces in a creative way and bring back nature as source of inspiration. It gives them an opportunity to work with hands in a computer era and to create low tech models with high tech logic. We thank our students for their unique ideas and their fabulous and ingenious models that are used in this paper.