# Teaching with Prototypes

## Learning architecture through making

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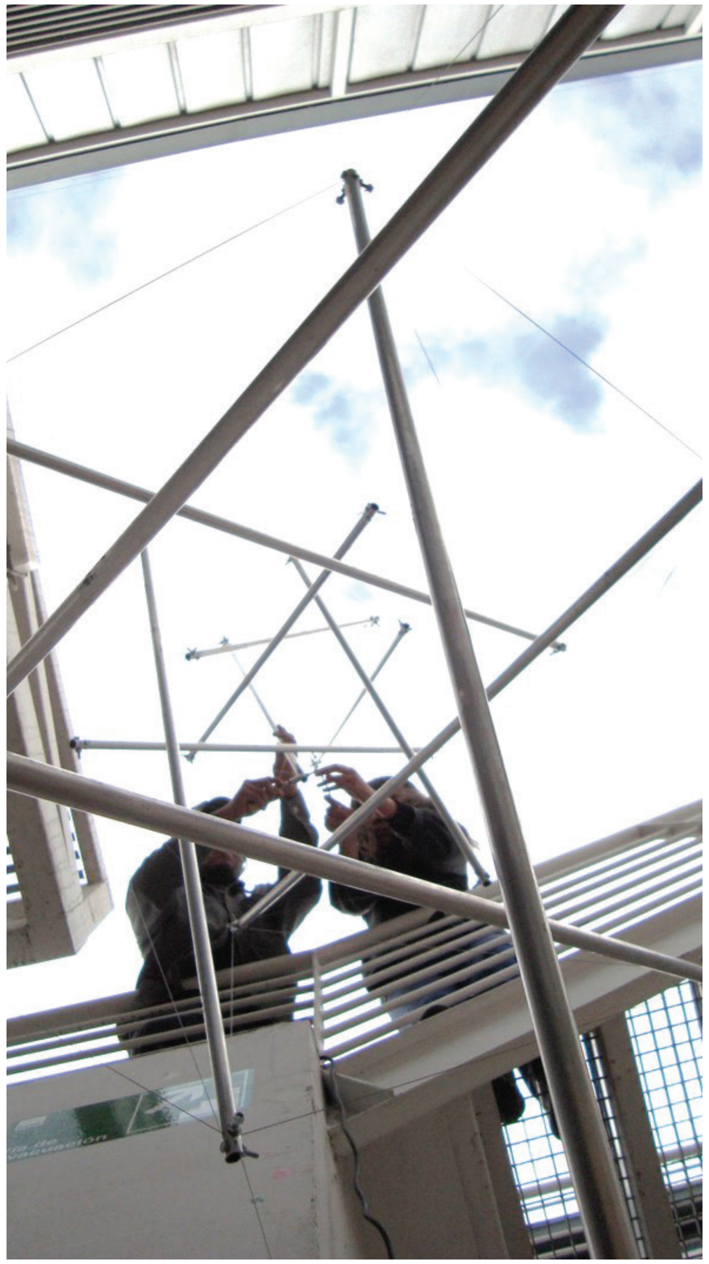
Within the context of architectural education, building construction and structures courses often share a common task: the agency of providing the object of design with its physical dimensions. Yet the realms of each field demand the use of specific teaching tools: abstraction, analytical methods, and numerical approaches for teaching structures; hands-on, know-how methods, and practical approaches for teaching building construction. Our primitive instinct of simplifying to learn forces us to highlight the essential components of what we call structure and construction. Their scopes, although juxtaposed in reality, increasingly diverge as we reduce the scale of actual buildings to fit them into classrooms. Seen as scaled-down physical entities, building components become simplified free-body diagrams in a course about structures, and orthographic drawings displaying finite and fixed arrangements of smaller parts in a course about building construction.

This somewhat speculative division begins to fade as we deal with objects that grow in size. Unlike a scaled-down model, a real-scale model brings on the effect of gravity. While maintaining the main features of a model, such as serving as a physical representation of geometric principles or informing a possible assembling sequence, working with prototypes enables students' cognitive agency with materials and building components. Students not only see them but also can touch, carry, move, and assemble them, getting the feeling of how much an object actually weighs. They can sense how rough or smooth a material's surface is. By using different materials, students learn how concrete cracks, steel rusts, or even how different types of wooden pieces smell; manipulation of the components—while prototypes are constructed—enables a learning process based on the physical interaction between human senses, material dimension, and building complexity.



1. Structural Models Workshops - tensegrity tower.

During their architectural education, students seldom have a chance to work with building construction materials. Moreover, they rarely experience the whole design cycle, which begins with conceptual elaborations and ends with a real-scale physical object. Working with material brings about the sense of material properties and an understanding of the basics of physics. Working with real-scale prototypes promotes an active learning environment, where students learn by making. The hands-on experience, knowledge, and skills they acquire through this process will enhance their design capabilities, raise awareness of their learning progress, and prepare them for the professional practice of architecture, which often demands graduate students with an understanding of the entire design process: from conception to delivery. While forming architects, selected teaching and learning strategies play a fundamental role in maintaining a delicate pedagogical equilibrium. On the one hand, the pressing need for improving the curricula of schools of architecture, making them shorter, more generalized, and aligned with cutting-edge technology developments, pushes instructors to choose methods relying on digital environments. On the other hand, the natural pace by which designers unfold the potential of creative thinking skills and problem-solving capabilities demands teaching methods whereby students physically engage with the subject of their learning.

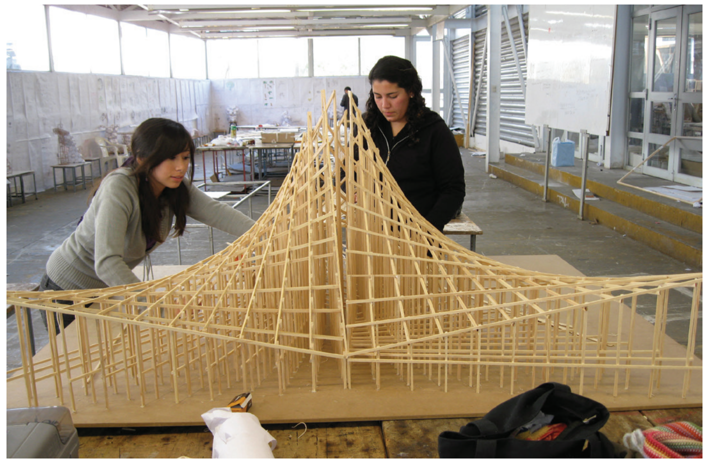
The use of hybrid fabrication techniques, which blend analogue or traditional construction methods with digital fabrication, enables expanding design explorations while speeding up the production process. This makes them suitable for developing prototypes or temporary structures in the context of architectural education. The resulting learning-by-making, supported by computational tools such as parametric design software, not only enhances design thinking through representation or making itself but also allows students to explore non-conventional geometries and structural forms. All of this leads to both potential innovations in pedagogy and potential contributions to the production methods in architectural design.

2. Temporary Paper Hy-Par Structure - moving to the installation area.

3. Voronoi Canopy – connecting the canopy with the column section.

4. Wind Machines – finalised prototype.

# Structural Models Workshop



1. Construction of the hyperbolic paraboloid formwork for ‘Los Manantiales’ shell structure.

2. Fabrication of one of the models in reinforced concrete.

3. Timber prototype of Fuller’s Geodesic Dome.

**Students from Structures and Building Construction Courses. Universidad Catolica del Norte, Antofagasta, Chile**

**Tutor: Mauricio Morales-Beltran**

A method for teaching structural typologies can be effectively based on the simultaneous and comparative study of multiple actual building cases. The rationale for examining more than two or three works as references is twofold: First, upon completion of the studies and construction of models, students can assess their assembling procedures by comparing results across different groups. The greater the number of models, the more diverse and informative the comparative framework becomes. Second, there is a practical constraint in forming students’ teams, as each case study requires the collaborative effort of, on average, ten students. Examining a larger number of cases broadens the research scope of various structural typologies. This approach offers the additional advantage of exploring different yet well-known materials, such as steel, reinforced concrete, wood, or even polymers.

The success of this method hinges on selecting structural typologies whose configuration relies heavily on a geometrical law or building pattern. Once students grasp this law or pattern, they not only understand the physical principle supporting such configurations but also gain insights into how to assemble the structure and determine feasible sizes for the model. The entire method is underpinned by a straightforward hypothesis: if it has been built before, we can build it again. Given that all the studied works are associated with geometry-based shapes, uncovering the order or geometric rubric governing the structural configuration proves useful for the subsequent practical process of drawing, cutting out, and sizing all the pieces of the model.

Consequently, the nature of the acquired knowledge, what students actually learn from the model, is defined by the dynamic act of performing a set of actions to construct the model. In other words, the learning process occurs in tandem with the hands-on experience of building the model. This approach emphasises a practical and experiential understanding of structural principles through the active engagement of students in the construction process.



# Paper Tower

1. Assembly process of the tower.

2. Fixing the last components of the tower before installation.

3. The final prototype of the water tower.

**Students: Paula Werblicka, Valeria Mazurkevich, Marcin Dudkowski, Orest Savytskyi, Karilina Fonfara, Maria Kęsy, Alicja Sienkiewicz, Ewa Hajducka, Karolina Dyjach. Wroclaw University of Science and Technology (WUST), Poland**

**Tutors: Peter Eigenraam, Mauricio Morales-Beltran**

Every year, natural disasters worldwide cause severe damage to urban infrastructure, leaving people without basic necessities such as shelter and drinking water. Recognising the significance of researching specialised solutions for emergency architecture in these threatened areas, a one-week workshop was organised for architecture students at WUST. The workshop aimed to design, optimise, and construct a water tower prototype made of paper tubes, intended to provide a post-disaster solution for victims. Students were tasked with utilising paper tubes to create a design solution with sufficient strength for use in a post-earthquake scenario. Initially, participants proposed tower designs, and the seismic response performance of these designs was evaluated using scale models subjected to ground motions produced by a custom-made shaking table. The chosen tower design underwent parametric studies to determine the most suitable geometry in terms of both form-finding and constructability. Computational modelling was employed to address challenges related to preventing clashes of building parts.

In the final phase, the students constructed a 1:3 scale prototype of the water tower. The chosen design was parametrically modelled, allowing for variations in the radii of the base circles and influencing the hyperboloid’s form. The source materials comprised 50 mm inner diameter paper tubes with a length of 2.2 metres. To achieve a tube length of 4.4 metres, logs were introduced at the end of two tubes. The six legs were assembled in a way that the tubes of each leg were separated by 180 degrees. The completed tower was temporarily installed in a fair area, positioned over a concrete podium. An OSB base served as the interface surface to anchor the tower to the concrete. Stability was ensured through the use of three cables.

The swift and intensive construction and assembly process provided an opportunity to refine the tower’s design and offered valuable insights to the students In regards to connection details when working with paper tubes.

# Temporary Paper Hy-Par Structure

1. Assembly process of the structure.

2. Installation of the hy-par structure in the university campus.

**Students: Mısra Kaçıral, Bilgesu Aksu, Berk Selamoğlu, Ayşenur Bozdağ, Damla Sezgin, Kaan Çetin, Can Yükselen, Cansu Ilkıç, Aslı Naz Atasoy, Melıh Kutsal, Furkan Özata, Dilan Kaya, Aybike Özdemir. Yasar University, Izmir, Turkey**

**Tutors: Form-Factory: Peter Eigenraam, Jerzy Latka, Mauricio Morales-Beltran**

This prototype of a gridshell made of paper tubes was the outcome of an experimental workshop organised by Form-Factory in Izmir. The aim of the workshop was to involve architecture students in the design and construction of a shading structure prototype made out of paper tubes, which would work as a temporary and informal meeting place. During the workshop, students had the opportunity to learn about form-finding methods, parametric design, shell structures, temporary architecture and paper-based structures. The first part of the workshop focused on designing a shell structure able to provide a shaded area for people to comfortably gather. The second part focused on the production of a 1:1 hyperbolic paraboloid (hy-par) gridshell structure using 64 mm diameter paper tubes. The three wings of this structure cantilevered about 5 metres over the green area. The shading structure prototype was temporarily installed in a green area on the university campus

The design and development processes were divided into several phases, beginning with conceptual design employing primarily hand sketches, scale model studies, and digital exploration. Material preparation and assembly followed, during which students explored the properties of the chosen material — paper tubes, known for being low-cost and easy to work with. This exploration stage included acquiring knowledge on the strength of paper tubes after failure, and techniques to provide them with sufficient waterproofing. As a result of the workshop, beyond the hands-on experience of building the structure, students acquired a range of new skills. These included teamwork, computational design of the hyperbolic paraboloid, operation of basic production tools, and solving technical problems, including issues related to temporary foundations, connection between elements considering friction, and impregnation



# The Gate

1. Assembly process of the beam section of The Gate.

2. Last adjustments to the column sections before assembly.

3. Design team and The Gate prototype installed in a public area in Izmir.

**Students: Esra Karatepe, Ezgi Leblebici, Berk Selamoğlu, Kaan Çetin, Hediye Kaya, Gizem Kılıç, Ceren Tuna. Yasar University, Izmir, Turkey**

**Tutor: Mauricio Morales-Beltran**

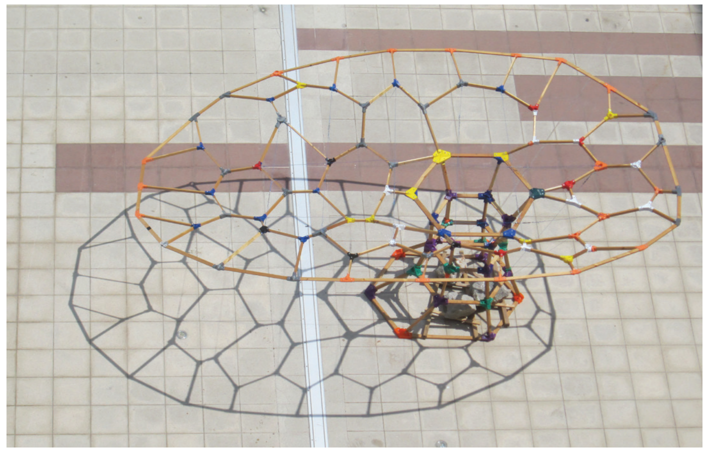
In the 'Advanced Construction and Structural Systems' course (Department of Architecture, YU), students had the opportunity to experience the whole design-to-production process of a piece of urban furniture, within the umbrella of hybrid fabrication. The course was organised as a 12-week workshop, where students were asked to design a free-form grid shell structure using a hybrid fabrication system of timber battens connected by 3D printed nodes. The aim of the workshop was to overcome the students' lack of practical experience in fabrication. By undertaking the construction of a large-scale project, students were expected to deal with several tasks of varying complexity, including design, structural analyses, planning, teamwork, and more. To achieve this goal within the tight schedule, a combined digital and analogue fabrication method involving the use of wooden battens and 3D printers was implemented. This hybrid fabrication method, established as a pre-condition for the design, not only facilitated hands-on experience but also equipped students with knowledge of computational design methods and skills in utilising digital fabrication tools.

The outcome of the workshop was The Gate, a freeform gridshell structure placed as a temporary installation in a public park. The structure materialized through a hybrid combination of 129 wooden battens and 68 Polylactic acid (PLA) 3D printed nodes, spanning 5 metres and reaching a height of 2.5 metres. For fabrication purposes, the structure was divided into three parts. The upper part – referred to as the beam- was built first as proof-of-concept. Simultaneously, the two other parts – the columns- were built and later assembled to the beam. Since it was planned as a temporary urban installation, no permanent anchoring system could be used to fix the structure to the ground. To keep the structure in place during the exhibition, rows of firebricks were placed next to the bottom bars of each column. The Gate remained in place for a week before being disassembled and reassembled for an exhibition at the university campus.

# Voronoi Canopy

1. Assembly process of the column section.

2. Assembly process of the canopy section.



3. The final prototype placed on the campus' main courtyard.

**Students: Gökalp Kalfa, Elif Kır, Ece Hepmutlu, Zeynep Diker, Emirhan Duğral, Zehra Çelik, Berkin Değirmenci, Ecenaz Adıgüzel. Yasar University, Izmir, Turkey**

**Tutor: Mauricio Morales-Beltran**

The Voronoi Canopy is the outcome of a design, fabrication, and assembly process of a free-form gridshell structure within the context of 'Advanced Construction and Structural Systems' course.
The construction of the prototype is based on an innovative hybrid fabrication technique that combines timber battens and 3D printed connections. The main advantage of this system is that it enables the production of freeform discrete structures using standard building materials and common available 3D printers. An additional challenge for the students was to design a structure that could be easily disassembled. For this purpose, students first explored design possibilities using digital and physical form-finding methods. After presenting their proposals, students chose one project to be further developed and implemented by the whole class. Following structural and fabrication requirements—such as a limit of 100 nodes—the final design of the canopy was completed.

The students designed the nodes considering 3D printing parameters such as filament type (PLA+ and PETG), time, infill percentage, and orientation. The main goals of these designs were to optimise for increased strength and to facilitate assembly with the wooden pieces. For these reasons, some nodes are designed as a single piece, while others were divided into two. The 3D printing strategy was determined by the assembly sequence: the supporting part—referred to as the column—was to be built first. Once the column was ready, the nodes for the canopy were designed and then printed. Due to the smaller section of the canopy bars, these smaller nodes were printed comparatively faster. The last nodes to be designed and printed were those connecting the canopy with the column, which were also the last components to be assembled to complete the structure.

# Wind Machines

1. Assembly process of the Wind Machine I.

2. Assembly process of the Wind Machine II.

3. Final prototype of the Wind Machine II.

**Students from the Universidad Catolica del Norte (UCN), Antofagasta, Chile**

**Tutors: Form-Factory: Peter Eigenraam, Jerzy Latka, Mauricio Morales-Beltran; UCN: José Guerra Ramírez, Felipe Rojas Ríos, Sergio Alfaro Malatesta, Carla Cáceres Collao**

The 2024 Form Factory International Design & Build Workshop was organised in collaboration with the School of Architecture UCN, Chile. The workshop focused on conceiving, designing, and building wind machines in Antofagasta. This city, situated on the border of the Atacama Desert, facing the Pacific Ocean and surrounded by high hills, provided a unique natural context for the development of proposals. Students were tasked with proposing wind machines that could establish a dialogue between the wind and other elements of nature, such as sunlight, water, and earth. This dialogue could be functional, metaphoric, or literal. Proposals could utilise the wind for propelling motion-based mechanisms, for example, inspired by Theo Janssen's strandbeesten, or to generate electricity through windmills. Additionally, proposals could incorporate playful elements, such as using the wind to produce sounds, music through a pipe organ, or propelling a small car carried by a kite.

During the workshop, the students conceptualised, designed, and built two pavilions that were installed on a beach in Antofagasta, Chile, facing the Pacific Ocean. These pavilions—the wind machines—were constructed with PVC tubes, chosen for their availability, weather resistance, and ease of assembly and disassembly.
The Wind Machine I was built with 130 mm diameter tubes arranged to create a whistle as the wind passed through. The orientation of this prototype in the chosen location followed the same principle, so that the predominant wind blows directly over the holes that produce the sound. The Wind Machine II used 50 mm diameter tubes, bent to create a vaulted shape. Colourful rags hung from secondary 25 mm diameter tubes, making the movement of the wind visible. People could actually 'feel' the embrace of the wind.