

# From physical to digital modeling: a case of study in the design of a space truss

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**Abstract:** *This paper is focused on how materials, modeled geometry and machinery can be related to study design and fabrication of spatial trusses. It is presented through an investigation carried by students of architecture as part of a class in materials. The objective of the class was to study a material in the context of Component Design; enhancing the principle of learning by modeling. In doing so, this document describes the techniques carried on by the students, assesses the results obtained, and discusses about the pertinence and alternatives to learn about component and assembly design.*

**Palabras clave:** Space truss, component design, modeling

## Introduction

The model making process is a path through which designers can understand concepts (Sass, 2005). In this class, modeling is the driver to integrate design and technology. Students learn to work with different media keeping up with technological innovations.

In an early stage of design, students work on physical based processes to gain knowledge making a mock-up. They learn about materiality, scale and geometry. Afterwards, they work with digital tools aiming to design an space truss in detail. Finally, students explore form generation and digital fabrication.

While most of the research studies through modeling that have been developed at the School of Architecture in Universidad de los Andes employ architectural scales, this class proposes a methodology to deal with aspects of real-world material fabrication and assembly methods, through 1:1 prototypes.

Research in material is focused on paper-tubes. These products are reused as structural elements. Their availability in various thickness and diameters, their capacity to be rapidly assembled and their low-cost are aspects that make them feasible for academic experimentation.

## Materials and Methods

This is an undergraduate class of 30 students who are taking the fourth year of architecture. The project consisted on designing and constructing a module for a space truss, this module is understood as a framework of lineal members connected together. In groups of three people, students built a prototype with a triangular arrangement of rods.

The material selected demanded research in geometrical and physical properties. There was a limited amount of paper tubes per group, it endorsed ideas about modular exploration. Over the span of two weeks, special emphasis is also given to digital modeling in Rhinoceros, generative modeling in Grasshopper, and rapid prototyping with a laser cutter VLS 660.

This section explains the sequence of stages in this project: physical modeling, digital modeling, parametrical modeling, and rapid prototyping. First, the students researched in the module design with the material. Second, the students examined geometrical possibilities of the system through grouping modules. Third, they explored parameterization to obtain form variation in the system. And fourth, they worked on rapid prototyping with special attention to node design.

## A. Physical modeling

At the physical modeling stage, students learn about material and structural constraints that take part in the design and fabrication of a prototype. It engages them with paper tubes and machine processes. These activities are similar to those used in construction to transform this material.

First of all, they research about materiality. A paper tube is an element made of a high graded raw material, and it is manufactured for industrial packaging using a spiral winding process. Because paper is an anisotropic material, the spiral winding process yields a generally anisotropic structure. Its properties vary widely when measured with the direction of the rolling or against it. Therefore, students design and construct a truss module with pin connections, loading tubes only with axial stresses. It permitted to avoid shear stresses on the cross section, and control the main failure modes: “V-buckle” and “sag” collapse.

Second, the students explore load transmission through assembling. There was a limitation in the amount of material. Each group had a 3m tube of 4” of diameter, and a 3m tube of 2” of diameter. They analyzed assemblage of elements with these lengths in a single layer or two layers assembly, managing to dimension edges, and angles in the vertex. The joint of rods had to be assumed to behave as a frictionless hinge, with this in mind, nails, screws and bolts were used as connectors between the tubes and the node.

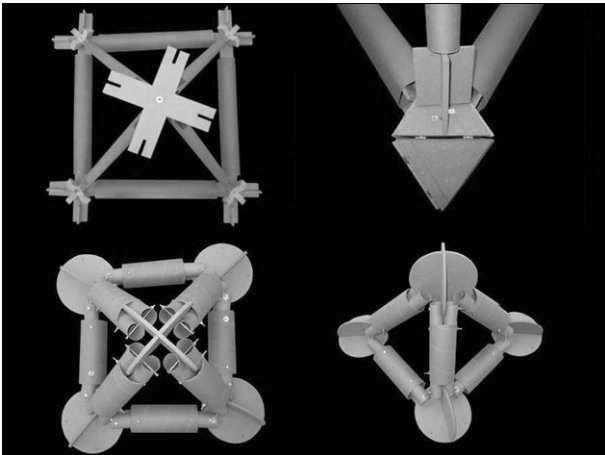


Fig. 1 Examples of prototypes developed by the students employing paper tubes

## B. Digital modeling

At the digital modeling stage, students become skilled in Rhinoceros. First, they learn how to construct appropriately geometry. They model the prototype construc-

ted on the previous stage, using Boolean operations to manipulate simple objects and derive more complicated ones. Precision on form features of rods and nodes is achieved through careful component design modeling. Multiplicity in assemblage solutions is obtained through thorough study of detailing.

Second, the students experiment in grouping polyhedrons connecting their edges. The modeled polyhedrons (tetrahedrons or pyramids) were grouped to obtain a particular form. Three shapes were given: a barrel vault, a simple frame, and a two cantilever structure, each student practice on grouping polyhedrons to constitute one of these truss geometries. A modular arrangement of rods permitted to have elements of single length to configure a space frame of desired size and form.

Third, the students focus on solving design variations at the node level. The types of nodes presented in the system are analyzed: corner nodes, one sided nodes, two sided nodes and frame support nodes. There were two main approaches to solve connections between rods. On one hand, nodes were based on Platonic solids with threaded holes in which the tubular sections were screwed. According to the number of rods that converged to the node, a specific solid was employed (i.e. tetrahedron, octahedron, or dodecahedron). On the other hand, nodes were based on interlocking layers in which tubular sections were fixed. According to the number of rods in the joint, two or more surfaces were attached; they were also sustained by friction.

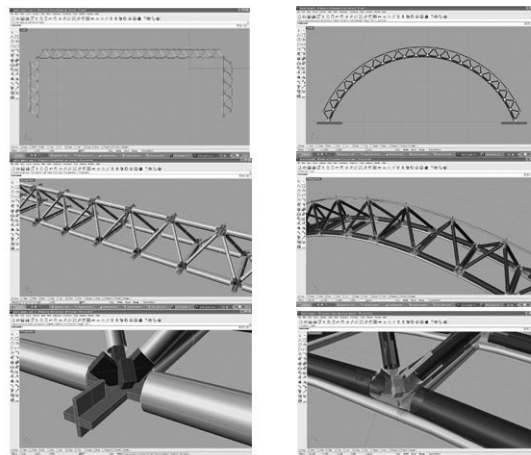


Fig. 2 Digital modeling in Rhinoceros

## C. Parametric modeling

At the parametric stage, students employ Grasshopper. This stage is intended to extend the geometrical possibilities when working with triangular frameworks. The

data from rods and nodes is used to perform actions that modify the overall geometry of the space frame, i.e. rod length and diameter, or node size and geometry are common parameters that can be controlled. The previous experience in Rhinoceros modeling points, curves, and Booleans becomes the basic knowledge to dispose a set of objects, defining data of parameters or actions in components.

First, students obtain information about the rods located on the top and bottom chords. A component creates points or intervals on the curves of the chords, these become the nodes of the truss. Second, students obtain web members through a component that creates line segments between the intervals of top and bottom chords. In this sense, there is a one-on-one matching algorithm connecting the inputs of the different chords. Finally, they modify curves (changing knot vectors location), or operations (increasing or decreasing the number of intervals) to transform the space truss.

Samples were analyzed according to their structural behavior. This allow students to comprehend that having new forms involve different stress magnitudes. For example, in the cases where span and geometry of the space truss were modified, forces on members changed. With the parametric modeling, they were able of modifying values such as depth of the space truss, and reducing member forces when depth was incremented.

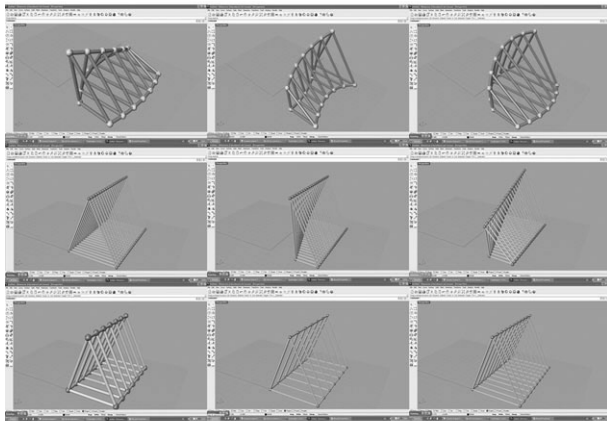


Fig. 3 Geometrical alternatives for a truss system

#### D. Rapid prototyping

At the rapid prototyping stage, students explore fabrication techniques. In this part, they detail one of the nodes of the space truss system; it is based on the resultant geometry obtained in the parametric modeling. This node model is constrained by material properties and available machinery. Students employ paper tubes on a laser

cutter VLS 660 to fabricate the parts that compose the connection between rods.

Limitations on machinery influenced the construction of the structural union. Students learn to work with architectural parts in full scale; detail design becomes a mater of decomposition. In most cases, strategies to prototype consist in subdividing geometry for fabrication. Furthermore, the work developed in the class examines non-orthogonal connections, and manufacturing processes. At the end, students survey for a more influential role of component design on the overall structural design.

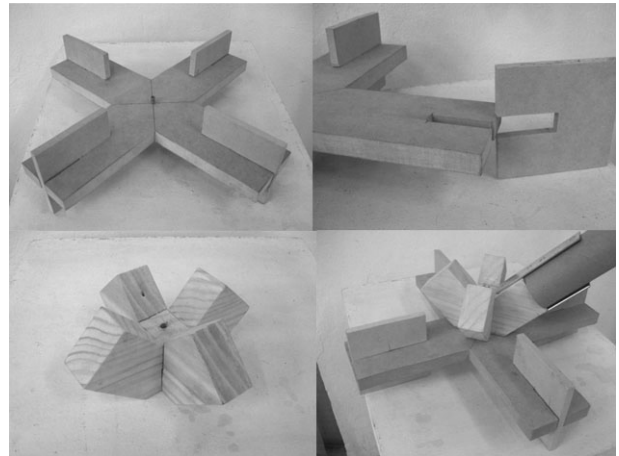


Fig. 4 Development of a connection fabricated with a laser cutter in wood and MDF sheets

## Results and Discussion

In design studios, the relationship between architecture and structure tend to be problematic. In various cases, student's proposals do not apply the technical knowledge taught in building technology courses, and without a comprehension of materials and structures, design lacks integrity. Consequently, this class endorses in their students research skills and teamwork, investigating in component design. Special attention is paid to the materialization of ideas, and the real life experiences through activity-based learning.

In the presented case study, undergraduate students approached to detail design through modeling. The objective of the proposed methodology was to interpret simultaneously different sorts of information, and encouraging new ways of teaching building technology in architecture. Stages were complementary; and students were able to experiment moving from one phase to the next one dealing with aesthetic and technical issues.

Awareness in using physical and digital modeling was considered essential by the students. Subjects such as: materials, geometry, and structure were studied employing different media. Mockups were built to test physical implementation of parts of the overall structural system using actual material at full scale, digital models were developed to represent structural configuration of space trusses, and parametric models permitted the study of geometrical possibilities.

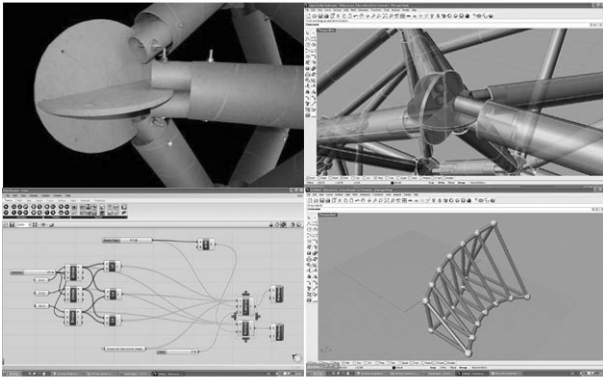


Fig. 5 Physical and Digital Modeling, stages of development of a space truss

On one hand, students were motivated towards constructing the physical prototype; they participated actively in the journeys at the materials lab. It did not take too long for them to familiarize with the properties of paper tubes, and the operation of the machines used to transform them. On the other hand, students had difficulties working with Rhinoceros. They complained about the complexity of the interface. However, after some days of using this software, they could envision technical aspects of the space truss system. Similarly, Grasshopper did not have a good start, but in the end the obtained results stimulated the initiative to continue testing with more variables.

Complexity on the space truss design was induced by the techniques used during the process. In each one of the stages, the number of variables increases resulting in models that contain more information about building. Modeling on Grasshopper permitted to deal with solutions for non-conventional space trusses. Therefore, connections with rods of different length and diverse angles between rods were attained.

Challenges that became evident with this work were related to material limitations and the application of rapid prototyping. Using paper tubes with CNC techniques to generate full-scale prototypes deserves more exploration. In some moment, it was difficult to manipulate

and transform paper tubes with the available laser cutter. Geometrical properties and material constraints have to be considered when operating special machinery. And more attention on digital fabrication can lead to study alternatives component design in a more creative way.

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