Course Title:

Geometry-based Structural Design
Material and Detail Computation for Structural Geometry

Fall 2022
ARCH 7320
Tuesdays 1:45pm - 4:45pm
Meeting location: MEYH321
Course outline

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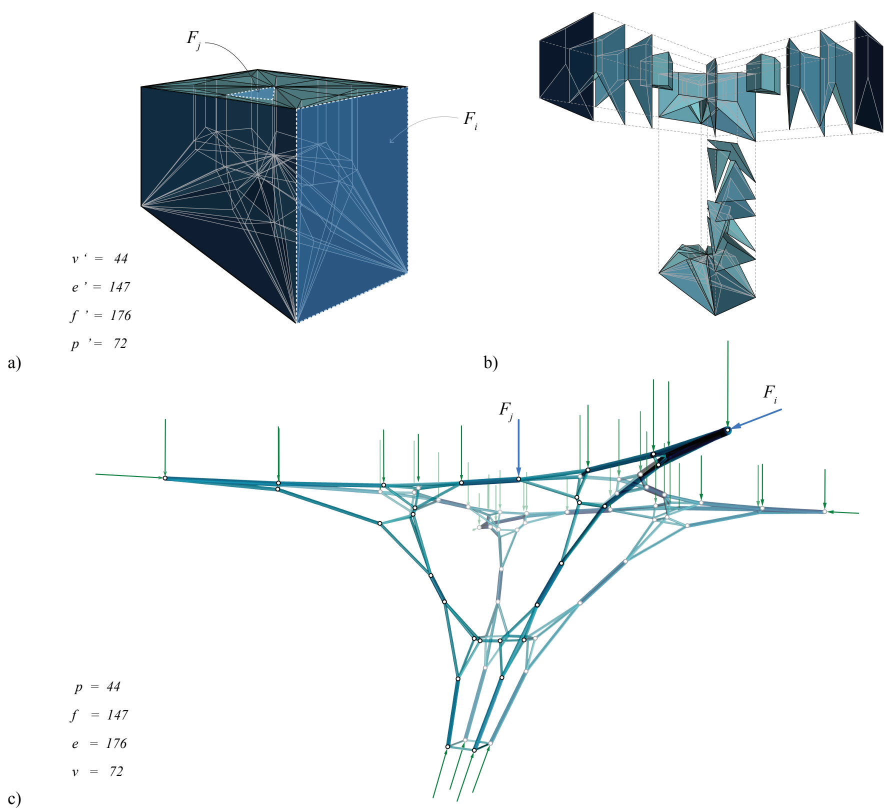

Figure 1: (a) Force diagram consisting of convex polyhedral cells; (b) the exploded axon of the force cells; and (c) the corresponding spatial funicular structural form.

1 Course description

Material Computation for Structural Geometry course provides a comprehensive introduction to novel geometric methods of structural design based on 2D and 3D graphical statics (Rankine, 1864; Maxwell, 1870; Wolfe, 1921; Akbarzadeh, 2016). The primary emphasis of the course will be on (i) developing a general understanding of the geometric representation of their internal and external equilibrium forces; and (ii) designing material tectonics based on the flow of forces in the system. Considering both force flow and material methods are necessary for designing efficient and innovative architectural structures. This semester, special consideration will be given to material and computational methods for the detail design of joinery and assembly process of spatial node. An appropriate fabrication techniques needs to be studied to construct the entire complex geometry of the structure.

Note that this course is based on ongoing research in the field of 3D graphical statics, and therefore provides students with the opportunity to directly contribute to the current research in geometric methods of the structural design. Familiarity with the parametric environment of Grasshopper is required, and code-writing ability is an asset. Particular attention will be given to structural model making and precise structural, architectural and assembly drawings. The outcomes of the course will become a primary collection of Polyhedral Structures Laboratory. Also, a unique summer research fellowship will be available for highly motivated students to build a one-to-one scale structural prototype based on the structural systems developed in the class.

2 Methodology

The course is divided into five consecutive parts with specific intentions; *Part I* will introduce the geometric principles of equilibrium of structural forms (Wolfe, 1921; Akbarzadeh et al., 2015a); *Part II* will focus on structural form finding using geometric techniques (Akbarzadeh et al., 2015c; Lee et al., 2016); *Part III* will concentrate in manipulating the geometry of the structural form and its force diagram to explore various architectural schemes (Akbarzadeh et al., 2015b; Akbarzadeh, 2016); and *Part VI* will specifically emphasize the choice of material and the fabrication techniques to construct complex spatial forms. Table 1 provides a brief overview for each part and its relevant aims and objectives.

2.1 Aims

Therefore the course has the following particular intentions:

- to introduce the concept of equilibrium using geometric techniques, expanding the reciprocal relationship between the elements of an equilibrated structural form and its force diagram;
- to emphasize the use of geometry in designing complex yet efficient structural forms and deriving the internal and external forces using geometric diagrams;

Course sections	*Aims*	*Objectives*
Part I: the principles of equilibrium	• introducing geometric equilibrium of forces in 2D and 3D; • hinting on the properties of form and force diagrams; • defining global and nodal equilibrium;	• to construct parametric form and force diagrams; • to represent different states of equilibrium geometrically;
Part II: form finding explorations	• introducing the technique aggregation in the force diagram; • describing the force subdivision technique; • providing the computational framework for form finding;	• to construct complex structural forms by designing their force diagram; • to produce various structural forms by redistributing the internal forces;
Part III: manipulating/articulating the design	• introducing geometric degrees of freedom of the form and force diagrams;	• iterative design process to fulfill specific architectural needs;
Part VI: materializing the structural geometry	• introducing various materials translating structural geometry into building components; • reviewing multiple fabrication techniques for constructing spatial structural geometry;	• to choose a specific material and translate the structural geometry into a volumetric object based on the properties of the chosen material; • to devise a proper fabrication technique for constructing the structural geometry;

Table 1: Various parts of the course and their aims and objectives.

- to simplify the understanding of complex structural concepts using geometric language instead of numerical methods; and,
- to investigate different materials and fabrication techniques to realize spatial structural forms .

2.2 Objectives

On completion of this course, students should be able to:

- describe the equilibrium of structural concepts using geometric methods of graphical statics in 2D and 3D;
- construct structurally informed, novel architectural concepts and derive the

internal and external forces in the system geometrically; and,

- understand the challenges in materializing spatial structural forms and develop appropriate fabrication techniques to construct their complex components (Jeska and Pascha, 2014; Lennartz and Jacob-Freitag, 2015; Weinand, 2016).

3 Grading

Table 2 provides the grading criteria of the course:

Assignment	*% of grade*	*Due date*
Session attendance	10	
Exercises	30	Sep 6, 27; Oct 4, 11, 25; Nov 1, 8, 15, 22; Dec 6, 13
Physical Prototype	40	Nov 30 – Dec 13
Final structural model	20	Dec 13
Force model	10*	

Table 2: Grading criteria;
∗ Additional points for the groups who build their force model for their final projects.

4 Lecture schedule

Table 3 represents the schedule as well as the tiles of the lectures of the course and their related exercises.

Session Date	*Week*	*Topics*
Sept 5	w1	Introduction to geometric methods of structural design
Sep 12	w2	Exercise on a parametric node and its force equilibrium
Sep 19	w3	Compression-only form finding: force subdivision and aggregation
Sep 26	w4	Exercise on compression-only form finding
Oct 3	w5	Compression-and-tension combined systems
Oct 10	w6	Exercise on combined system of forces
Oct 17	w7	Convex hull, Extended Gaussian Image and the data structure of a node
Oct 24	w8	Mid-term review: physical, structural model and proposition for the building block
Oct 31	w9	Material geometry: computational design workshop
Nov 7	w10	Exercise on section development
Nov 14	w11	Structural performance assessment
Nov 21	w12	Exercise on structural analysis
Nov 28	w13	Assembly techniques and strategies
Dec 5	w14	Exercise on the assembly and part to whole relationship
Dec 12	w15	Final review

Table 3: Lecture schedule with specific dates for exercises, midterm, and final review dates.

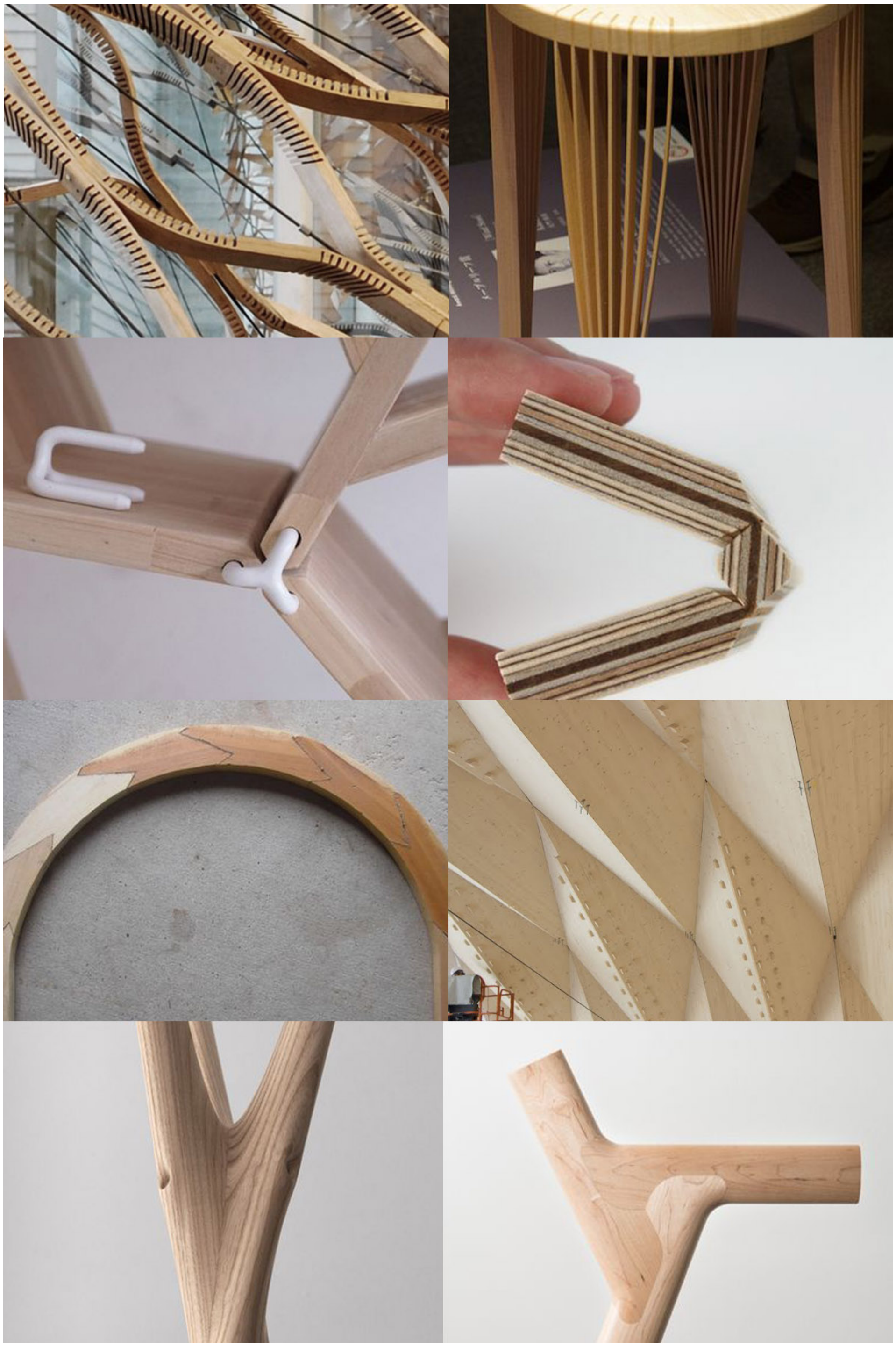

Figure 2: Various joint detailing and fabrication techniques applicable to structural timber.

5 Mid-term Requirements

The primary objective of this exercise is to propose a construction technique that translates the funicular design network into material(s) composition, either a single or a hybrid system. It would be essential to identify the constraints of machining and the limitation of material and offer design methods to address them.

5.1 List of Deliverable

The following items are necessary for the mid-term presentation.

- A presentation file in the format of PowerPoint including the following sections: (i) introduction, expanding on the type of construction material and precedents that incorporated the materials in the design of building systems; (ii) form-finding exercise and the description of the problem to span 5x5 meter columns; (iii) the constraints of the machine or materials; (iv) the proposed technique to materialize the funicular network.
- The physical prototype of the construction and fabrication logic method that identifies the construction challenges/opportunities for the final structure by the end of the semester.
- The documentation of the entire work in the form of a PDF file in the following format: (1) use a letter size document in its portrait form; (2) consider 1″ margin from each side and include two vertical columns for the text with gutter size of 1/4″.

References

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M Akbarzadeh, T Van Mele, and P Block. On the Equilibrium of Funicular Polyhedral Frames and Convex Polyhedral Force Diagrams. *Computer-Aided Design*, 63:118–128, 2015a.

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