Course Title:

Geometric Structural Design
3D graphic statics to fabrication

Fall 2018,
ARCH 732-003
Thursdays 2-5 pm; Room 324
Course outline

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PSL

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1 Course description

Geometric Structural Design 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 developing a general understanding of the relationship between structural forms in equilibrium and the geometric representation of their internal and external forces. This link is the main apparatus for designing provocative structural forms using only geometric techniques rather than complicated algebraic/numerical methods. Moreover, special consideration will be given to materialization of the structural geometry and the proper fabrication techniques to construct the 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 structural design. Familiarity with a parametric software is required, and code-writing ability is an asset. Particular attention will be given to structural model making and careful structural 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 forms 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.

3 Grading

Table 2 provides the grading criteria of the course:

Assignment	*% of grade*	*Due date*
Session attendance	10	
Exercises	30	Sep 14;28, Oct 19, Nov 2; 16, 30
Structural model	40	Nov 30 – Dec 7
Fabricated prototype	20	Dec 7
Force model	10*	

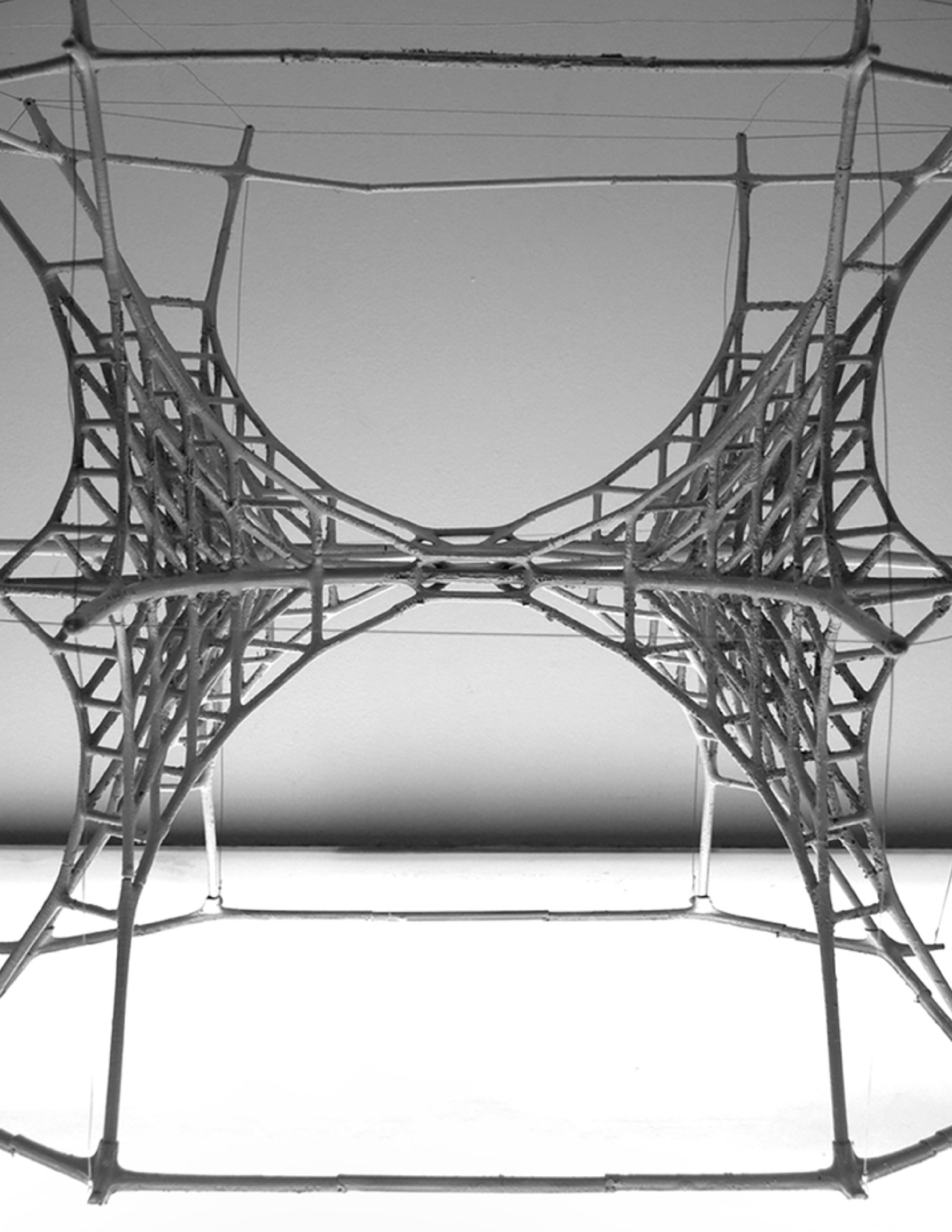
Table 2: Grading criteria;
∗ Additional points for the groups who build their force model for their final projects.

4 Lecture schedule

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

Course Sessions		*Titles*
Part I: Intro		
Aug 31	w1	Introduction to geometric methods of structural design
Part II: Form finding techniques		
Sep 7	w2	2D structural form finding; Exercise 1: aggregation/subdivision
Sep 14	w3	Review Exercise 1
Sep 21	w4	3D graphic statics; Exercise 2: aggregation
Sep 28	w5	Review Exercise 2
Part III: Articulating the design		
Oct 12	w6	3D Graphic Statics; Exercise 3: subdivision
Oct 19	w7	Review Exercise 3
Oct 26	w8	physical form finding; Exercise 4: sectional model of the structure
Nov 2	w9	Midterm review
Part IV: Materializing the design		
Nov 9	w10	Exercise 5: fabrication technique
Nov 16	w11	Review Exercise 5
Nov 22	w12	Exercise 6: assembling parts
Nov 30	w13	Review Exercise 6
Dec 19	w14	Final Review: a complete conceptual model and one-to-one scale prototype

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



References

M Akbarzadeh. *3D Graphic Statics Using Reciprocal Polyhedral Diagrams*. PhD thesis, ETH Zurich, Zurich, Switzerland, 2016.

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.

M. Akbarzadeh, T. Van Mele, and P. Block. 3d graphic statics: Geometric construction of global equilibrium. In *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium*, Amsterdam, The Netherlands, 2015b.

M Akbarzadeh, T Van Mele, and P Block. Three-dimensional Compression Form Finding through Subdivision. In *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium*, Amsterdam, The Netherlands, 2015c.

J Lee, T Van Mele, and P Block. Form-finding Explorations through Geometric Transformations and Modifications of Force Polyhedrons. In *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2016*, Tokyo, Japan, September 2016.

J C Maxwell. On reciprocal figures, frames and diagrams of forces. *Transactions of the Royal Society of Edinburgh*, 26(1):1–40, 1870.

W J M Rankine. Principle of the Equilibrium of Polyhedral Frames. *Philosophical Magazine Series 4*, 27(180):92, 1864.

W S Wolfe. *Graphical Analysis: A Text Book on Graphic Statics*. McGraw-Hill Book Co. Inc., New York, 1921.