Welcome to 01.110 Computational Fabrication

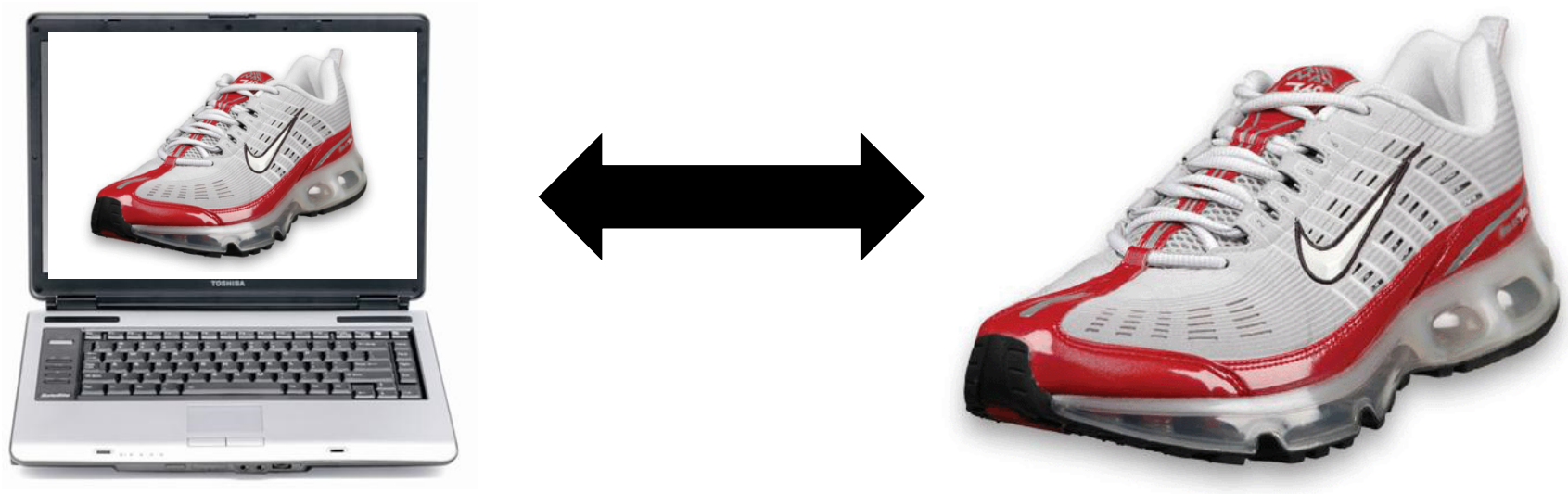
Sai-Kit Yeung

ISTD

Plan

- Overview of computational fabrication
- Administrivia
- Overview of the semester
- Overview of the assignments
- Overview of the labs
- Sample projects

What is computational fabrication?

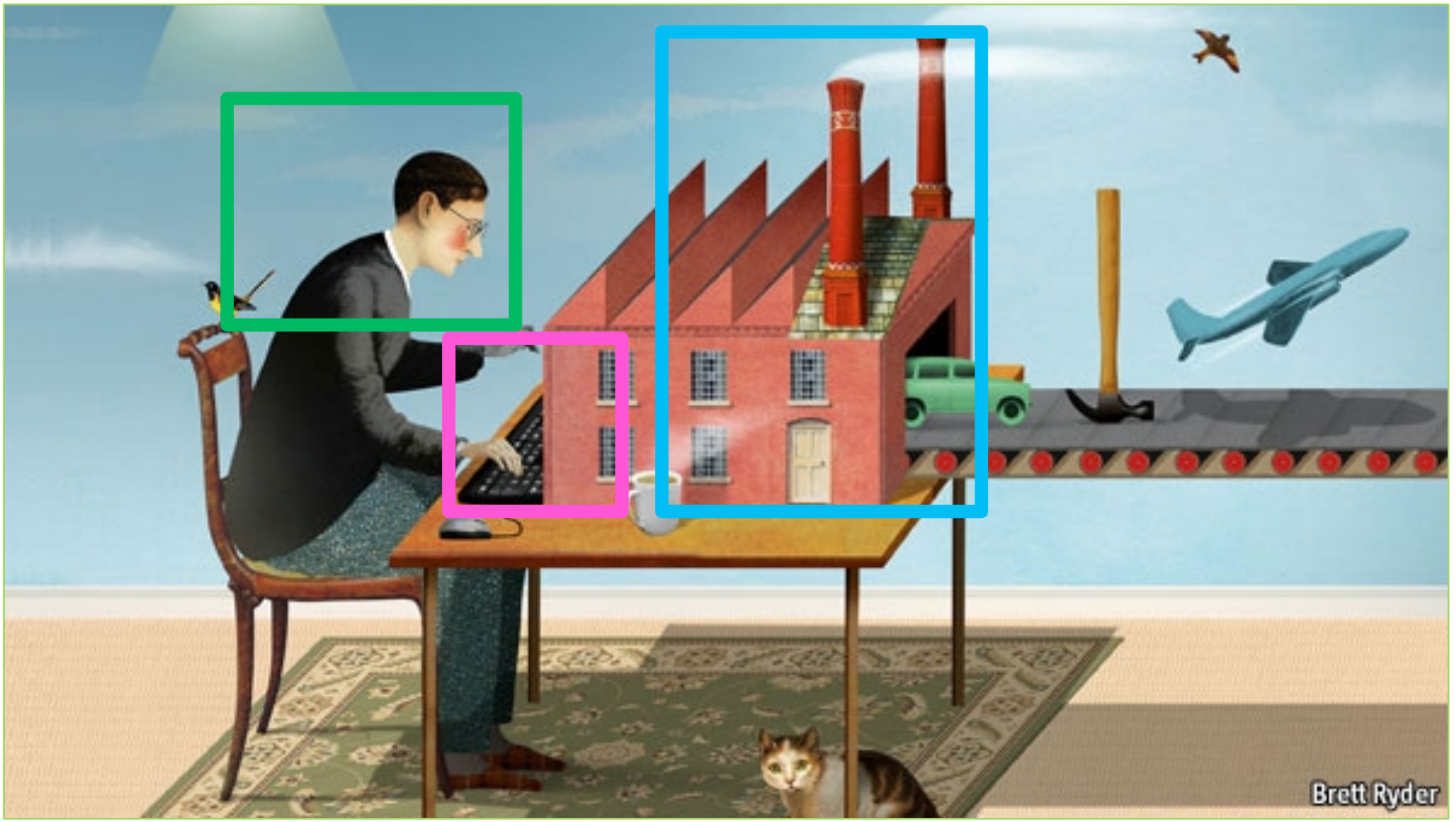


A Third Industrial Revolution

The Economist (Cover)

A Third Industrial Revolution

The Economist (Cover)



Enthusiasm


The Economist
Europe loses the mobile-phone war
Africa's new wealth
Japan's tea party
How to switch off the internet
The shoe-thrower's index
FEBRUARY 12TH-18TH 2011
Economist.com
Print me a Stradivarius
The manufacturing technology that will change the world
This violin was made using an EOS laser-sintering 3D printer (and it plays beautifully)

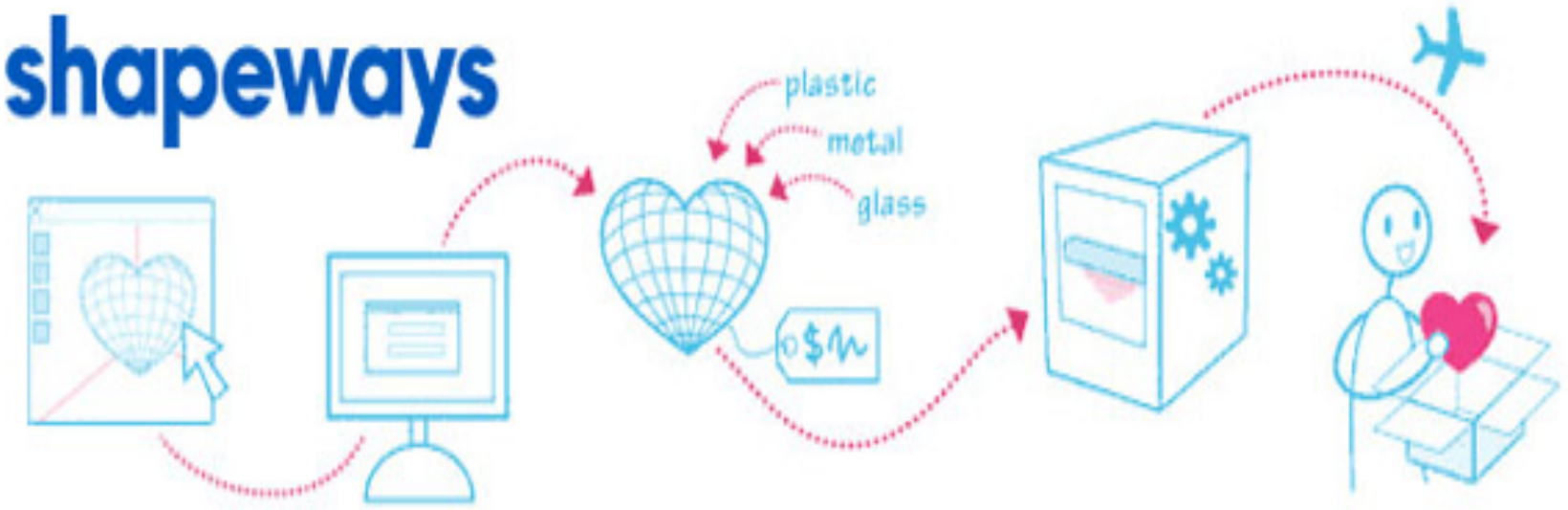

Mit Stellenmarkt
c't magazin für computer technik
€ 3,90
11
Räumlich scannen mit Kamera oder Kinect
Kopieren in 3D
Gratis-Software • Webdienste • 3D-Drucker im Test
Die große CPU-Übersicht
Konkurrenz für Google Maps
Quad-Core-Smartphone
SkyDrive, Google Drive
3D-TV ohne Brille
55 Alternativtinten im Test


REVIEWS
Dell Precision M6600 Mobile Workstation
HP Z210 CMT Desktop Workstation • ArchiCAD 15
SolidWorks 2012 • TurboViewer DWG Viewer for IPad
COLUMNS
Circles and Lines: Associative Arrays Updated
CAD Manager: Explain Your Value to Management
User Profile: Drafter Adam Sharratt Takes on AutoLISP
Fall 2011 | Vol. 28 No. 3 | $9.99
cadalyst
Get Productive with CAD and Get the Job Done.
www.cadalyst.com
3D Printing Within Reach
Affordable, versatile options put technology in the hands of professionals and consumers
Tech Trends:
BIM Supports Rise of Supertall Structures


THE DESIGN ISSUE
INSIDE NERF • MAKING GORILLA GLASS • BUILDING A SKYSCRAPER IN 15 DAYS • ETSY GOES PRO
WIRED
MAKE BELIEVE | OCT 2012
THIS MACHINE WILL CHANGE THE WORLD
This man [MAKERBOT'S BRE PETTIS] will show you how.
Print amazing objects at home!
THE NEW REPLICATOR 3-D PRINTER

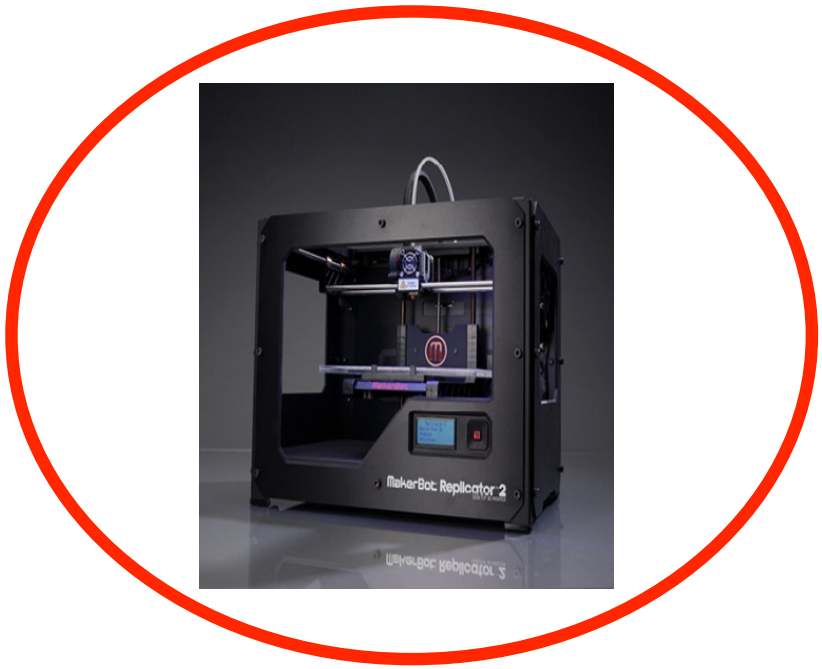
Game Changers

- 3D Printing Services



Game Changers

OBJET Connex
$250K



MakerBot Replicator 2
~$2K

More units sold per month
than OBJET Connex ever

Game Changers

Mainframe

Personal Computer

Singapore's future in 3-D

- $500 million fund
- 5-year "Future of Manufacturing" plan announced in 2013
- SUTD Digital Manufacturing and Design (DmanD) center - $25 million fund for phase 1.

THE STRAITS TIMES HOME | B7

3-D printing was identified as one of the advanced manufacturing technologies that will be supported by a $500 million fund set aside by the Government under its latest five-year "Future of Manufacturing" plan announced during Budget 2013. **Hoe Pei Shan** finds out what 3-D printing is and how it can help cement Singapore's place as an advanced manufacturing hub

Singapore's future in 3-D

How does 3-D prototyping and manufacturing work?

MISSING a wrench in your toolbox?

Or need a new doorknob to replace the one you just broke?

With a 3-D printer, you could be printing these items in fully functional form – typically in either plastic or metal – on your own, at home, and with little technical expertise (see box).

The 3-D printing technology in its basic use for rapid prototyping – in which a scale model is produced to test a product concept – has been around for several years.

But cutting-edge advances in this technology over just the last two years are helping to produce highly customised and intricate products such as lifelike artificial human ears, plastic cars, and even printed inhabitable homes, leaving the world intrigued and in awe.

United States President Barack Obama said 3-D printing "has the potential to revolutionise the way we make almost everything", a point he made in his State of the Union address last month.

Finance Minister Tharman Shanmugaratnam echoed Mr Obama's sentiments in his Budget speech last month when he highlighted 3-D printing as one of two types of technological advancements that are changing global manufacturing and that would be developed under a five-year $500 million "Future of Manufacturing" initiative to help ensure Singapore "remains a key global centre for advanced manufacturing".

News of the initiative – overseen by the Economic Development Board – has been received with enthusiasm by industry insiders who say that 3-D printing is still very much in its infancy in Singapore, despite having taken the world by storm.

"Its potential benefits and applications have not been well-realised by the Singapore manufacturing industry," said Dr Saeed Maleksaeedi, a leading research scientist at the Singapore Institute of Manufacturing Technology who specialises in materials science and engineering.

The 3-D printers in Singapore are mainly found in companies and educational and research institutes that employ prototyping applications rather than manufacturing, he added.

There are currently only a handful of companies here that provide 3-D printing hardware and software – mostly imported – and essentially two that actually offer commercial 3-D printing services, said Mr Benoit Valin, director of one such firm, Prototype Asia.

But the companies say that demand for such services, largely from creative product design and consumer and industrial electronics, is growing, and the Government's latest manufacturing initiative appears to be timely.

"Any later and we would be lagging behind – this is the perfect window of opportunity for Singapore as interest has built up and the technology is fairly advanced and affordable now," said Mr Terrence Oh, Asia-Pacific regional director of EOS, one of the world's biggest makers of 3-D printers. He notes that the price of mid- and low-end 3-D printers has dropped sharply over the past two years, with machines that once cost US$20,000 (S$25,000) now available at US$1,000 or less.

According to Dr Maleksaeedi, the real magic in 3-D printing lies in how the technology can be used for manufacturing high-value-added products across all sectors, from biomedical, aerospace and precision engineering to fashion and jewellery.

hpeishan@sph.com.sg

WATCH THE VIDEO
www.straitstimes.com
See how 3D printing works
Download a QR code reader app on your smartphone and scan this code for more information

STEP 1: 3-D imaging 3-D blueprints used for printing can be custom-designed, downloaded from open-source libraries, or 3-D scanned. Here, Mr Cheong Beng Huat (left), manager of INTED (which imports and sells 3-D scanners and rapid prototyping solutions), uses a hand-held 3-D scanner to create a 3-D image of reporter Hoe Pei Shan at local start-up 3D Matters.

STEP 2: Texturising The scanned 3-D image needs to be texturised, smoothing out flaws or data gaps to form a complete 3-D image of the reporter, using software. The final image will then be sent to the 3-D printer.

STEP 3: Printing Composite plastics-based powder is deposited in microscopic layers, with the desired shape in each layer bonded by a glue-like solution. The printed layers build up to produce a 3-D object.

STEP 4: Cleaning The excess powder is vacuumed and dusted off, revealing the printed 3-D bust.

FINAL PRODUCT: Glue is applied on the bust to complete the final step of bonding.

ST PHOTOS: KEVIN LIM

Regulations needed to prevent weapon printing

THE immense potential of 3-D printing brings exciting possibilities but also ... ture or deal in guns, arms and explosives without a licence, but EOS Asia ... going on", said Mr Oh. "Anyone can access open-source blueprints for weapons, and it is hard ... they hope to see a clear regulatory framework accompanying the development of 3-D printing in Singapore.

http://www.straitstimes.com/the-big-story/asia-report/singapore/story/singapores-future-3-d-20130318

What do you expect to learn?

What you will learn in 01.110

- Advanced modeling methods
  - Geometry processing
  - Solid modeling
  - Simulation (Kinematics, FEM)
- 3D Printing
- 3D Scanning
- Latest research in computational fabrication
  - Analysis of papers published at ACM SIGGRAPH/ SIGGRAPHAsia

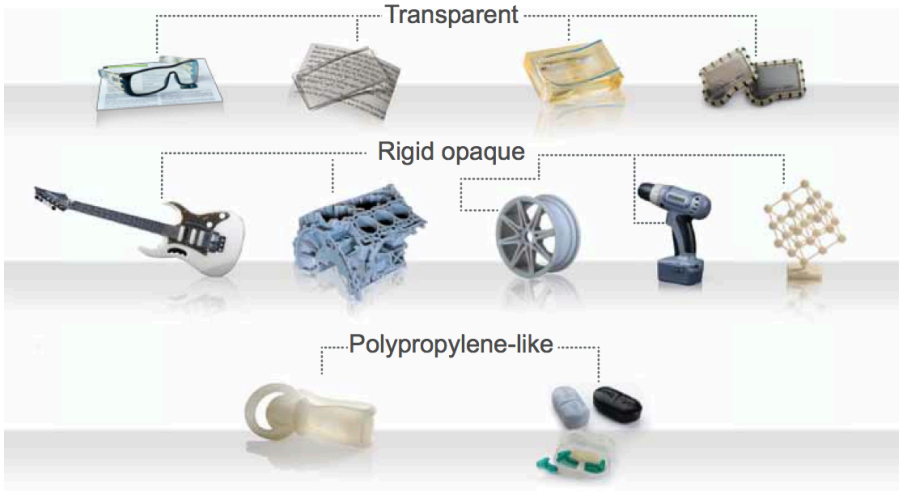
What are the challenges?

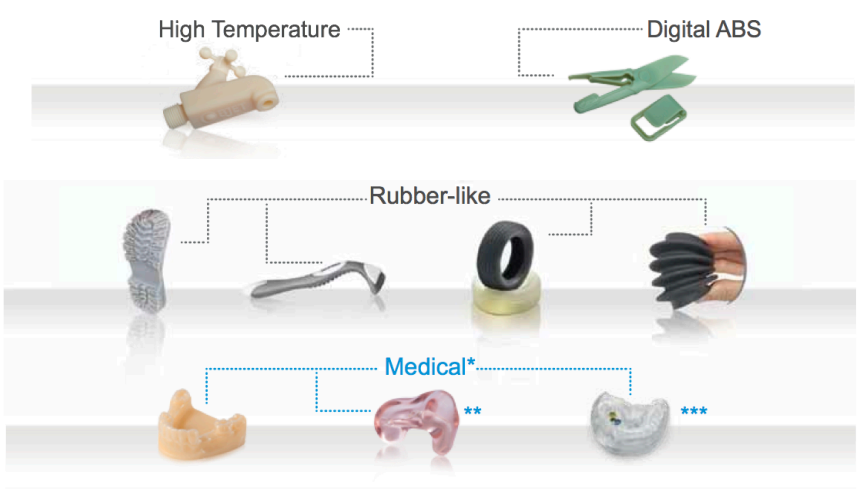
Hardware Challenges

- Slow
  - Printing 5’’ x 5’’ x 5’’ object takes 10+ hours
- Expensive
  - $100 / lb
- Size

Materials

- Large material library
  - But printing with some materials is difficult

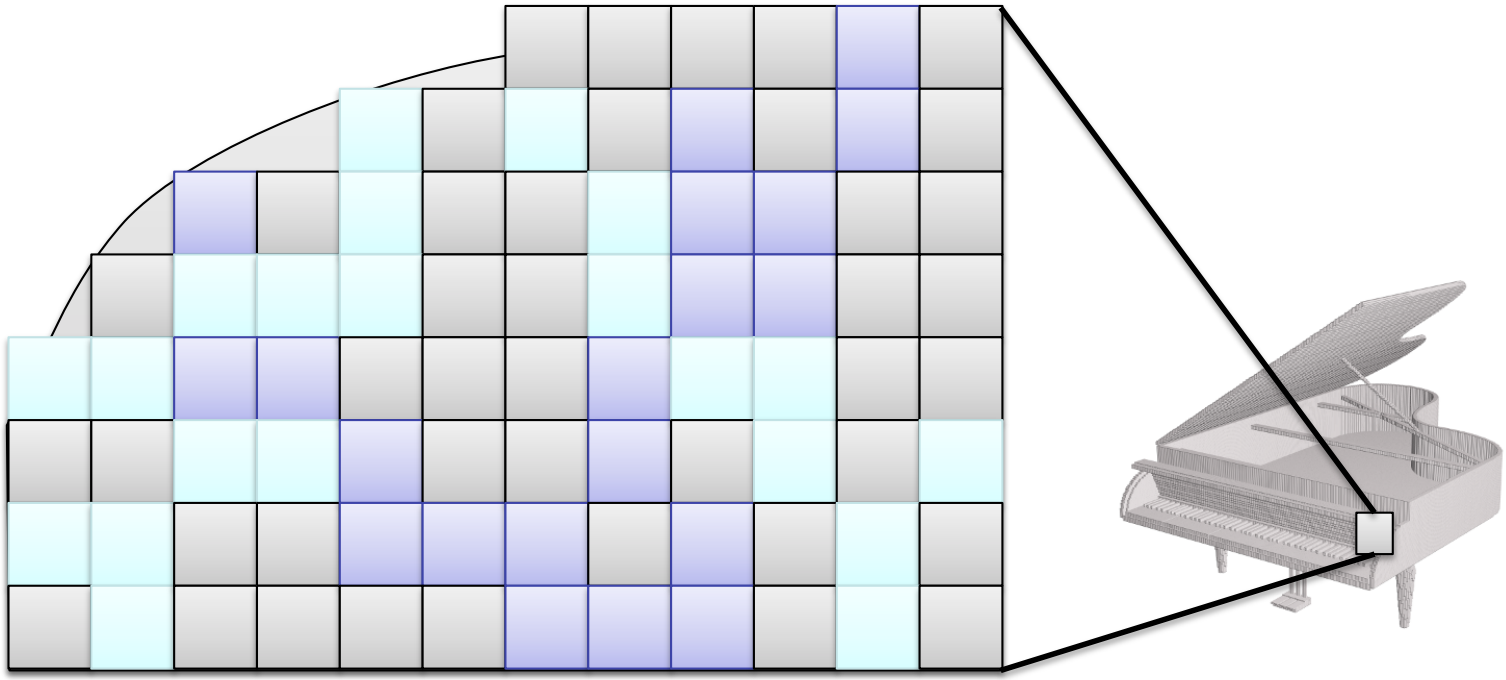




Courtesy of Stratasys

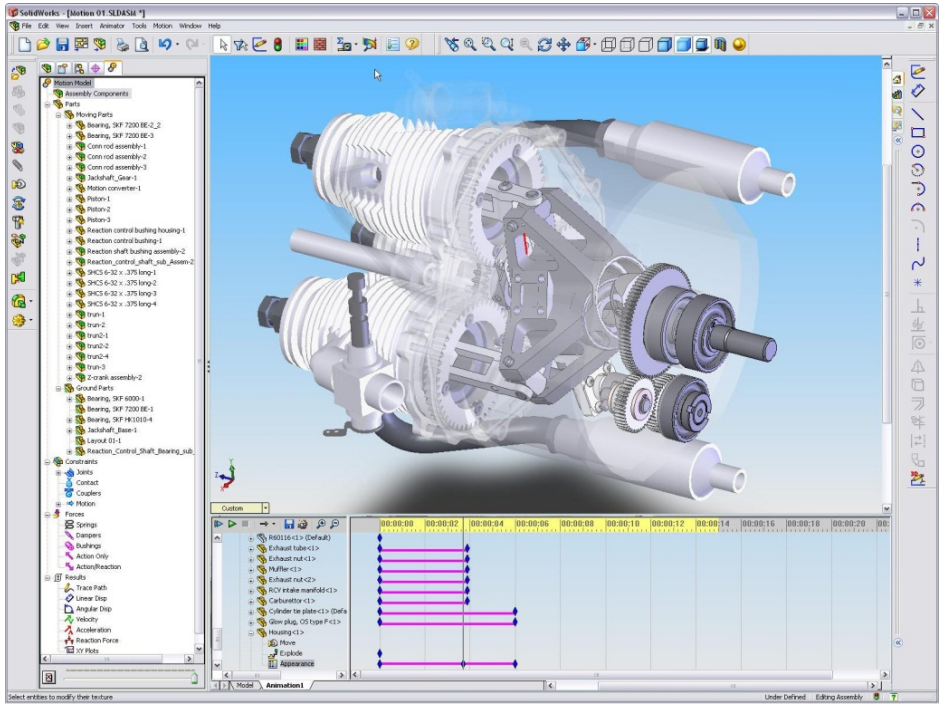
Software Challenges: Data Requirements

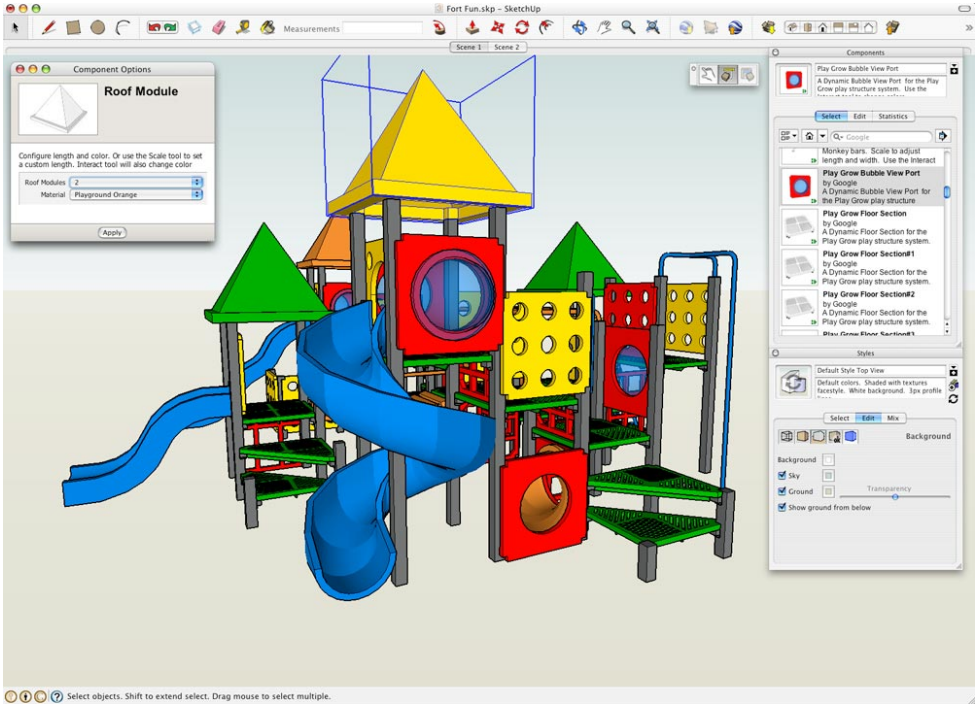
- Giga voxels/inch^3, Tera voxels/foot^3



Challenges: Modeling Interfaces for the Masses

- 3D modeling packages are not adequate for the general population

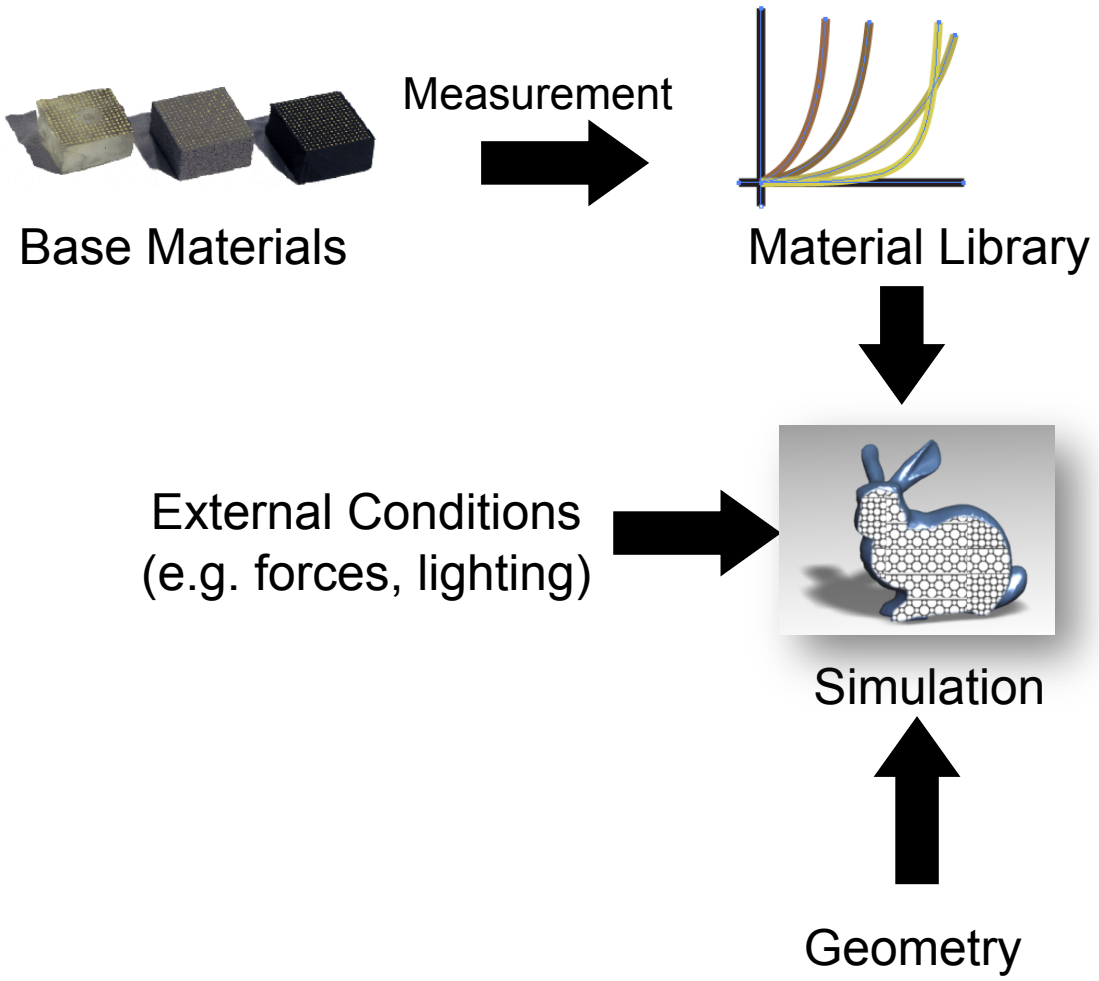




Challenges: Modeling Materials

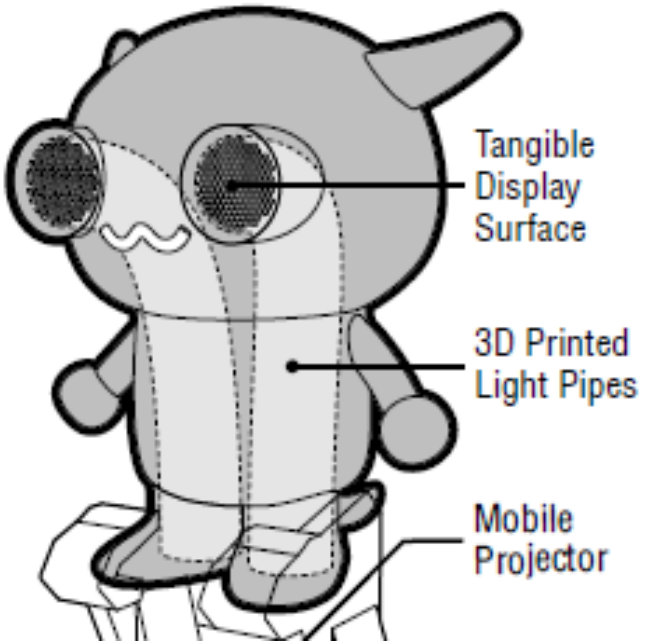
- Focus on 3D geometry
- Currently one material per part
- How to model parts composed of many materials?

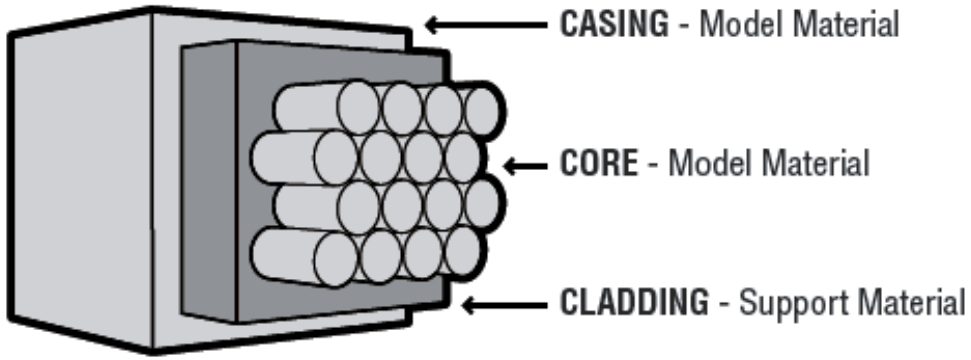
Print Preview: Measurement and Simulation



Applications: Fabricating Refractive Materials

Willis et al. 2012





Applications: Fabricating Refractive Materials

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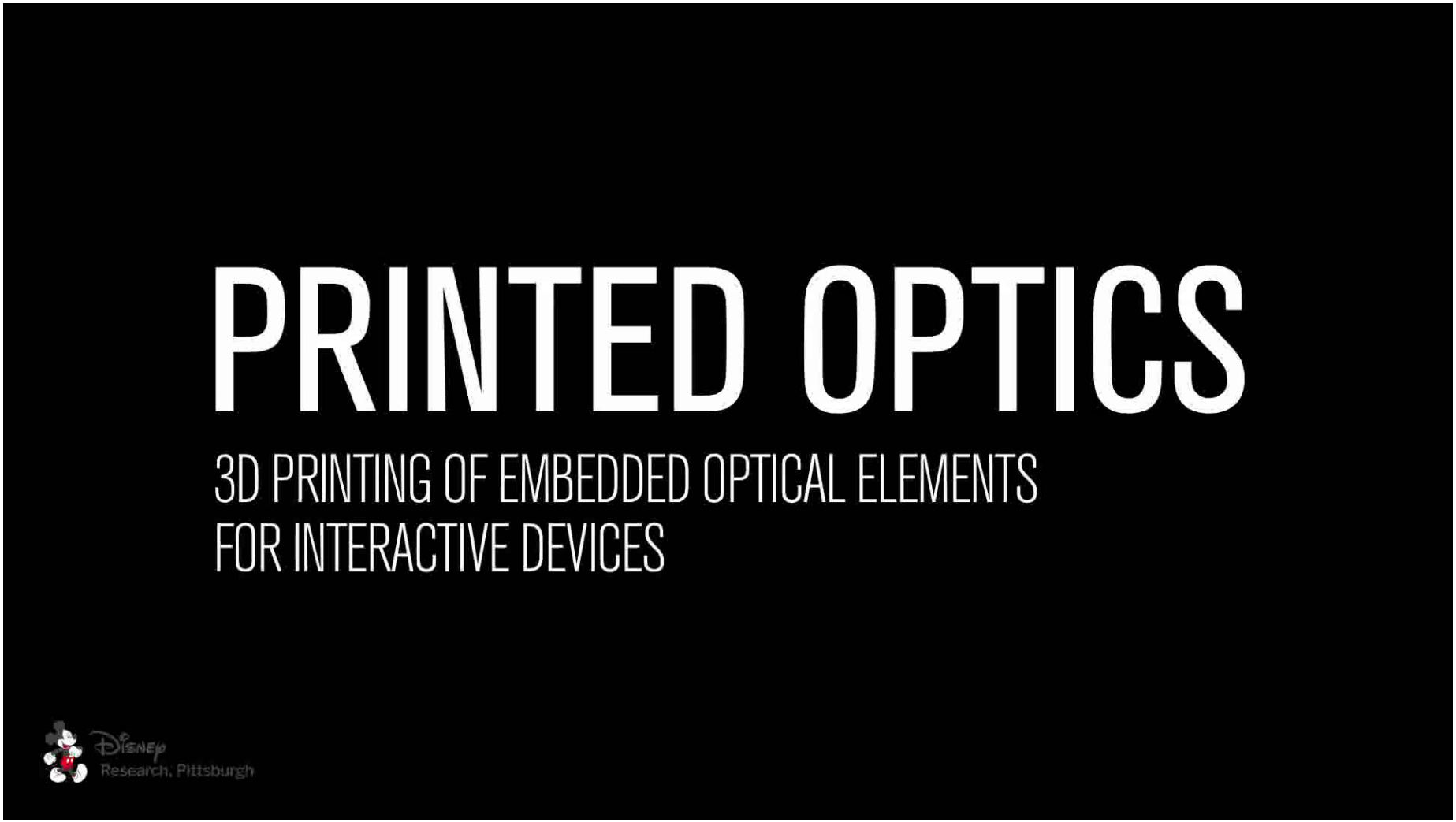
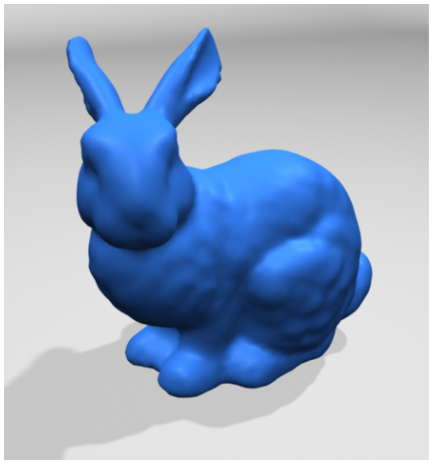
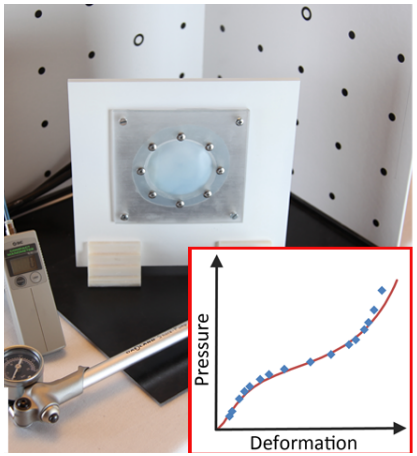


Applications: Perfect Balloons

Skouras et al. 2012



Input



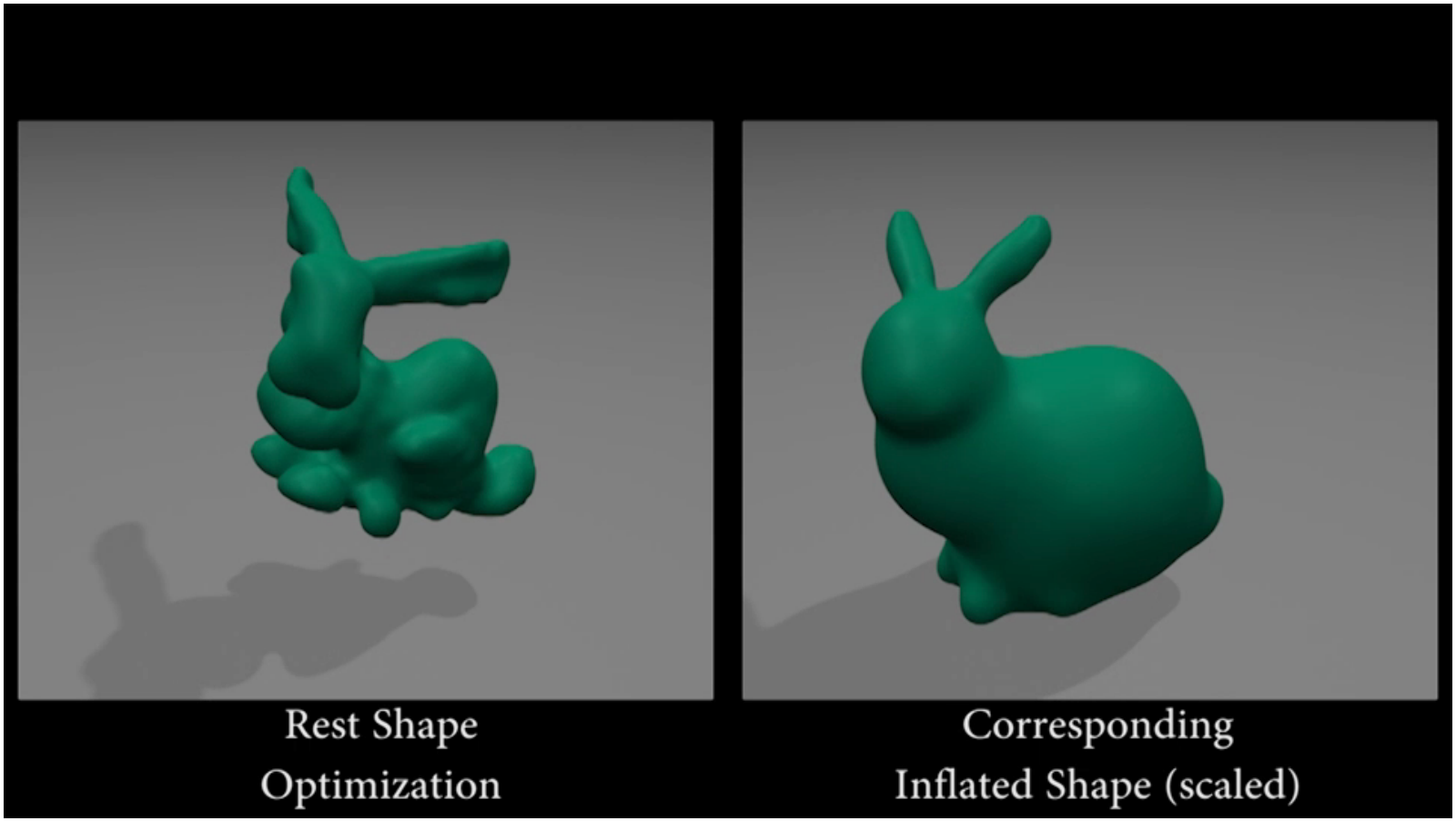
Measurement

Optimized Balloon

Not optimized Balloon

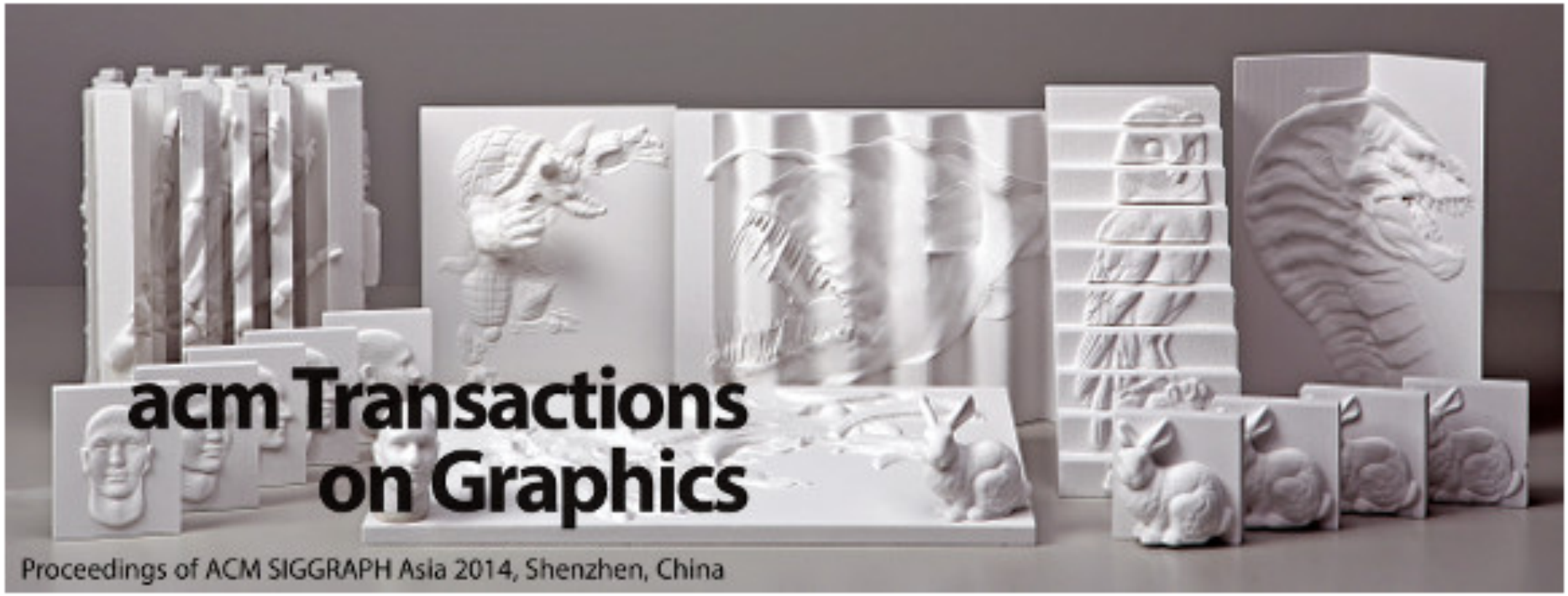
Applications: Perfect Balloons

Skouras et al. 2012



Applications: Appearance-Mimicking Surfaces

Schuller et al. 2014



Applications: Appearance-Mimicking Surfaces

Schuller et al. 2014

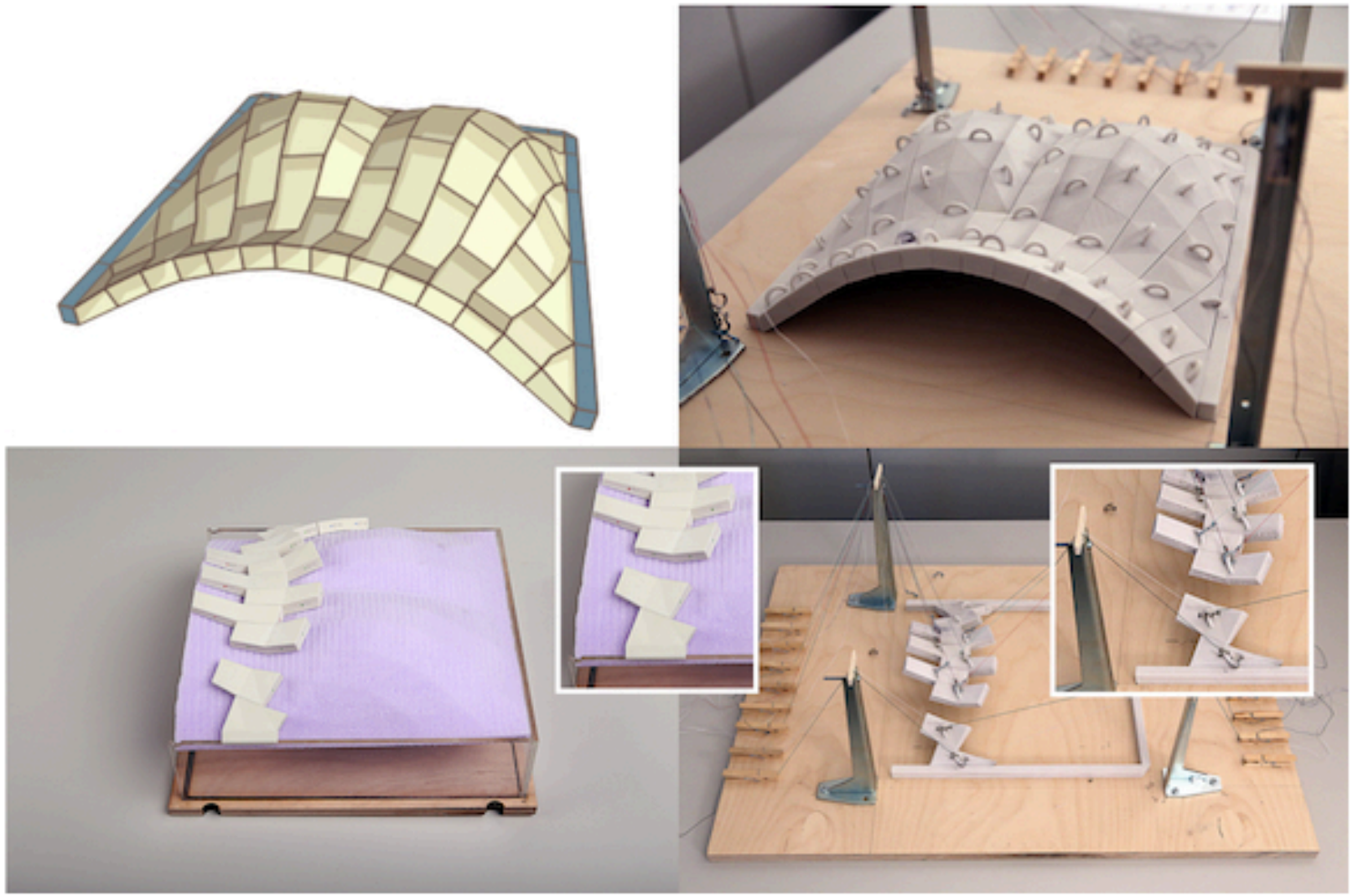
Appearance-Mimicking Surfaces

Christian Schüller Daniele Panozzo Olga Sorkine-Hornung

ETH Zurich

Applications: Assembling Self-Supporting Structures

Deuss et al. 2014



Plan

- Overview of computational fabrication
- **Administrivia**
- Overview of the semester
- Overview of the assignments
- Overview of the labs
- Sample projects

Registration

- The course will be offered regularly
- Satisfies Technical Application Elective (TAE) requirement
- B or above in Digital World, or instructor's approval

Source

- Courtesy to Prof. Wojciech Matusik at MIT
  - Leading expert in computer graphics and computational fabrication
  - Provides majority of the course materials

The Team

- Instructor
  - Sai-Kit Yeung
- Co-Instructors
  - Oliver Weeger
- TA
  - Quang-Hieu Pham
  - Benjamin Kang

Schedule

- Cohort Class
  - Monday 3:30pm-6pm (Class or Lab, check email/ webpage)
  - Wednesday 11:30am-1pm
  - Thursday 10:30am-12noon
  - Think Tank 10, Room 1.416
- Lab
  - Monday 3:30pm-6pm (not every week, 4 in total)
  - Fab Lab/Characterization Lab

Communication

- Course website at people.sutd
  - http://people.sutd.edu.sg/~saikit/courses/01.110
  - Announcements
  - Slides (posted before/soon after each lecture)
  - Assignments, Labs instructions
- E-dimension
  - Nanoquiz, Assignments, Labs reports turn-in
- Email
  - saikit@sutd.edu.sg, oliver_weeger@sutd.edu.sg, quanghieu_pham@sutd.edu.sg, benjamin_kang@mymail.sutd.edu.sg
  - Preferred method of communication

Grading Policy

- Assignments and Labs: 50%
  - 4 assignments (must be completed individually)
  - 4 labs (done in groups)
- Project: 40%
  - Project proposal + presentation: 6%
  - Mid-point report + presentation: 10%
  - Final presentation and report: 24%
- Nanoquizes: 10%
  - At the beginning of most lectures
- No midterm/final

Prerequisites

- No strict prerequisites
- 50.017 desired
- All assignments require some programming
  - C++, Matlab, OpenSCAD
- Calculus, linear algebra
  - solving equations, derivatives, integrals
  - vectors, matrices, basis, systems of equations

Assignments

- Start immediately
- Turn in a report
- Turn in code and executable
- Collaboration policy
  - The assignments should be done **individually**
- Late policy
  - Due @ 11:55pm
  - They may be submitted late by no more than 24 hours, weekend and holiday counted. The penalty for late submission is 20% of the score
  - Medical problems must be documented

Assignments

- Student Conduct:
  - [Important] Students are required to adhere to the University Policy on Academic Standards and Cheating, to the University Statement on Plagiarism and the Documentation of Written Work, and to the Code of Student Conduct.
  - [Important] Also note that posting projects or solutions on public websites requesting or offering to pay for outside assistance is strictly prohibited. It is also not allowed to publicly post your solutions, even this is for free, as it allows other students to copy them and hence results in plagiarism. These are all serious academic dishonesty. Students (whether past or current students) involved in these activities will be identified and sanctioned with no exception.
  - [Important] If Plagiarism is confirmed, straight F will be given to the final grade. Academic warning will be given with potential academic probation for repeated cases.

Assignments

1: Voxelization (C++)

- out May 12th, due May 26th (11:55PM)

2: Procedural Geometry (OpenSCAD)

- out May 26th, due June 9th (11:55PM)

3: Kinematics (Matlab)

- out June 9th, due June 16th (11:55PM)

4: FEM simulation (Matlab)

- out June 16th, due June 30th (11:55PM)

Labs

- Labs will be in the Fab Lab
- Done in groups (2-3 students)
- Turn in a report
- Monday 3:30pm-6pm Fab Lab
  - Not every week!

Labs

1: 3D scanning (May 23th)

2: Basic 3D printing (June 6th)

3: Linkage fabrication (June 13th)

4: 3D printing and testing of flexures (June 27th and July 4th)

Projects

- Project proposal presentations + report (6%)
  - Presentation and Report due July 7th
- Mid-point project report (10%)
  - Presentation July 20th, Report due July 21st
- Final project presentations (10%)
  - August 3rd
- Final Project report (14%)
  - due August 10th

Projects

- Meet with us early to discuss project ideas!
- Projects should have a substantial computational component
- Projects should have some connection to the real world
- Projects should be done in a group

Questions?

Plan

- Overview of computational fabrication
- Administrivia
- **Overview of the semester**
- Overview of the assignments
- Overview of the labs
- Sample projects

Overview of the Semester

- Learning the basics (till the recess week)
  - Solid Modeling
  - 3D Scanning
  - 2D & 3D Printing
  - Simulation
  - Optimization
- Case studies (after the recess week)

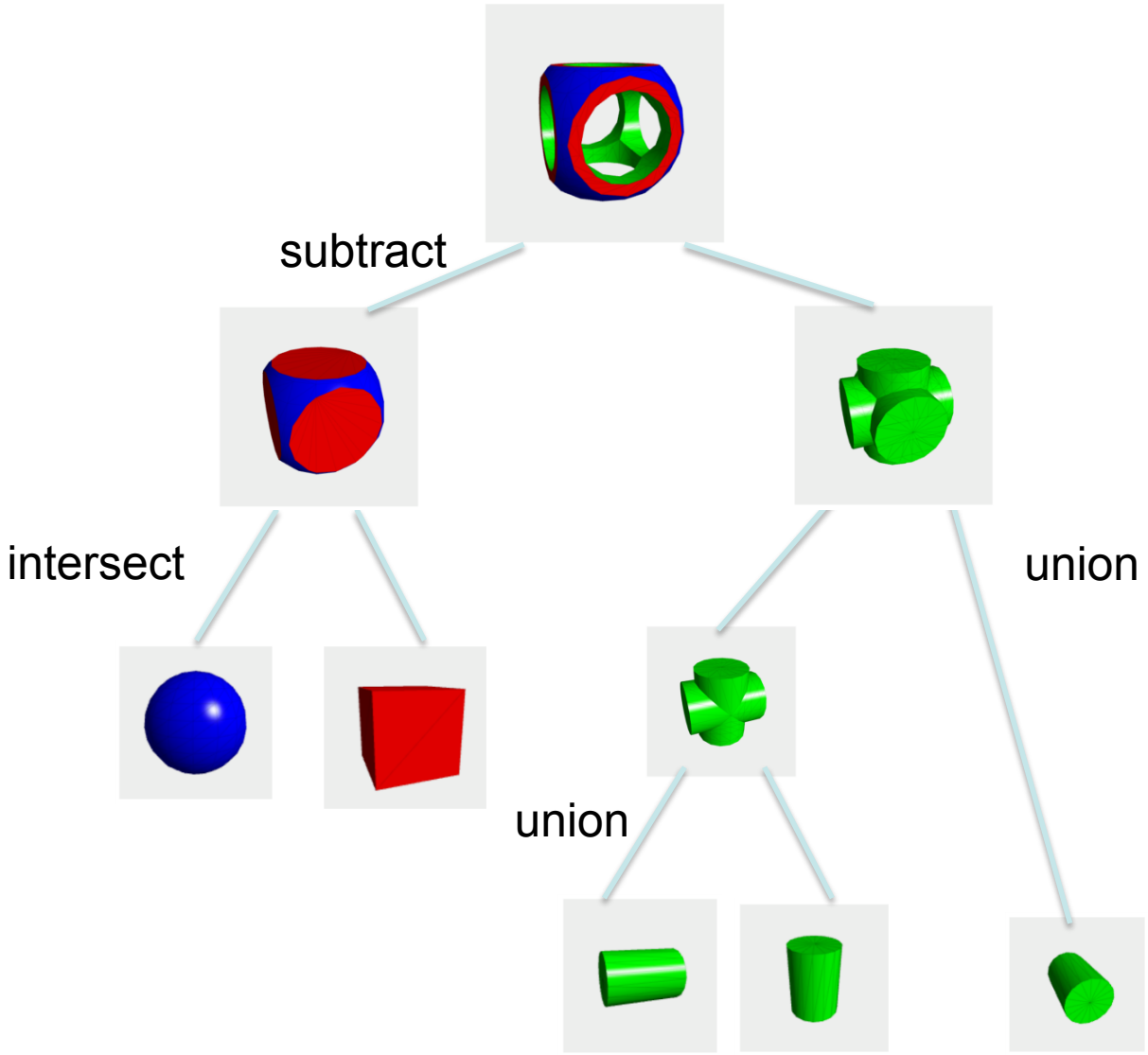
Solid Modeling

- Represent solid interiors of objects

Visible Human
(National Library of Medicine)

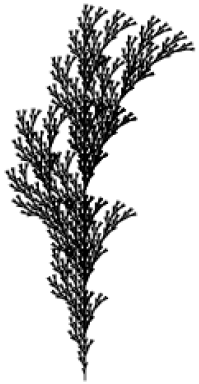
SUNY Stony Brook

Constructive Solid Geometry (CSG)

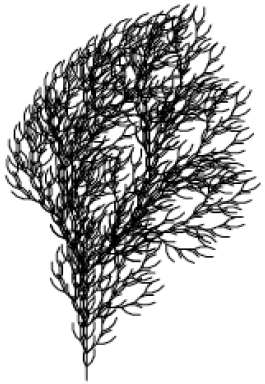


Procedural Geometry

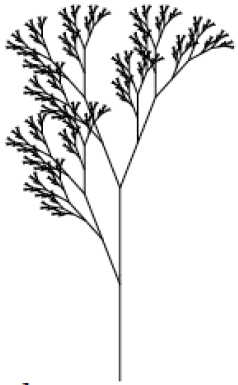
a
n=5, δ=25.7°
F
F→F[+F]F[-F]F



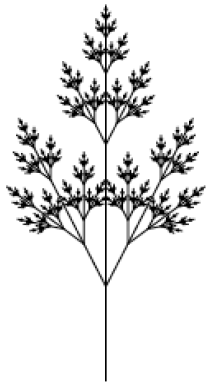
b
n=5, δ=20°
F
F →F[+F]F[-F][F]



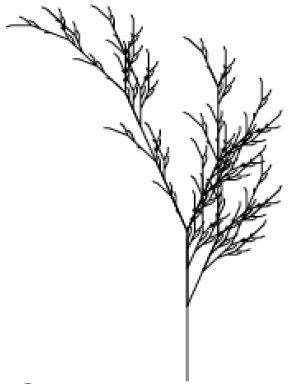
c
n=4, δ=22.5°
F
F→FF-[-F+F+F]+
[+F-F-F]



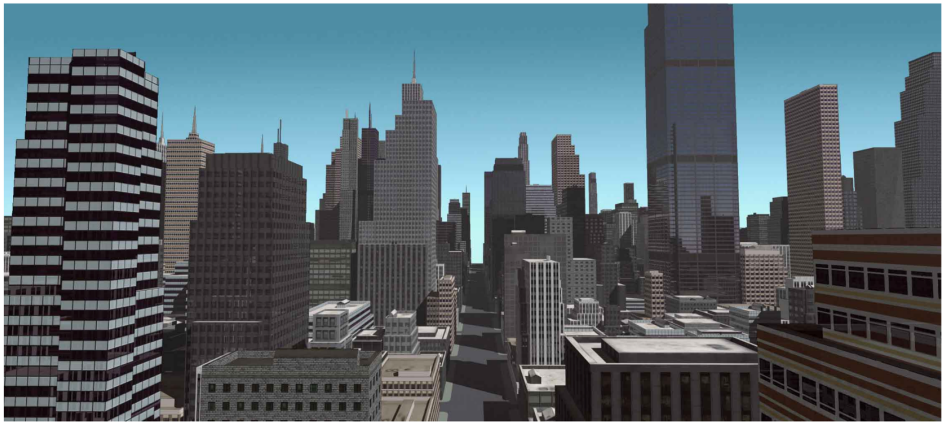
d
n=7, δ=20°
X
X →F[+X]F[-X]+X
F →FF

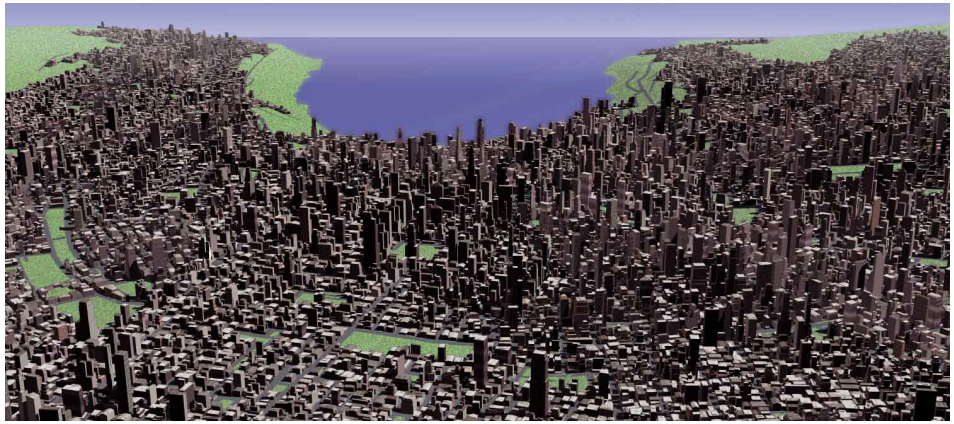


e
n=7, δ=25.7°
X
X→F[+X][-X]FX
F→FF

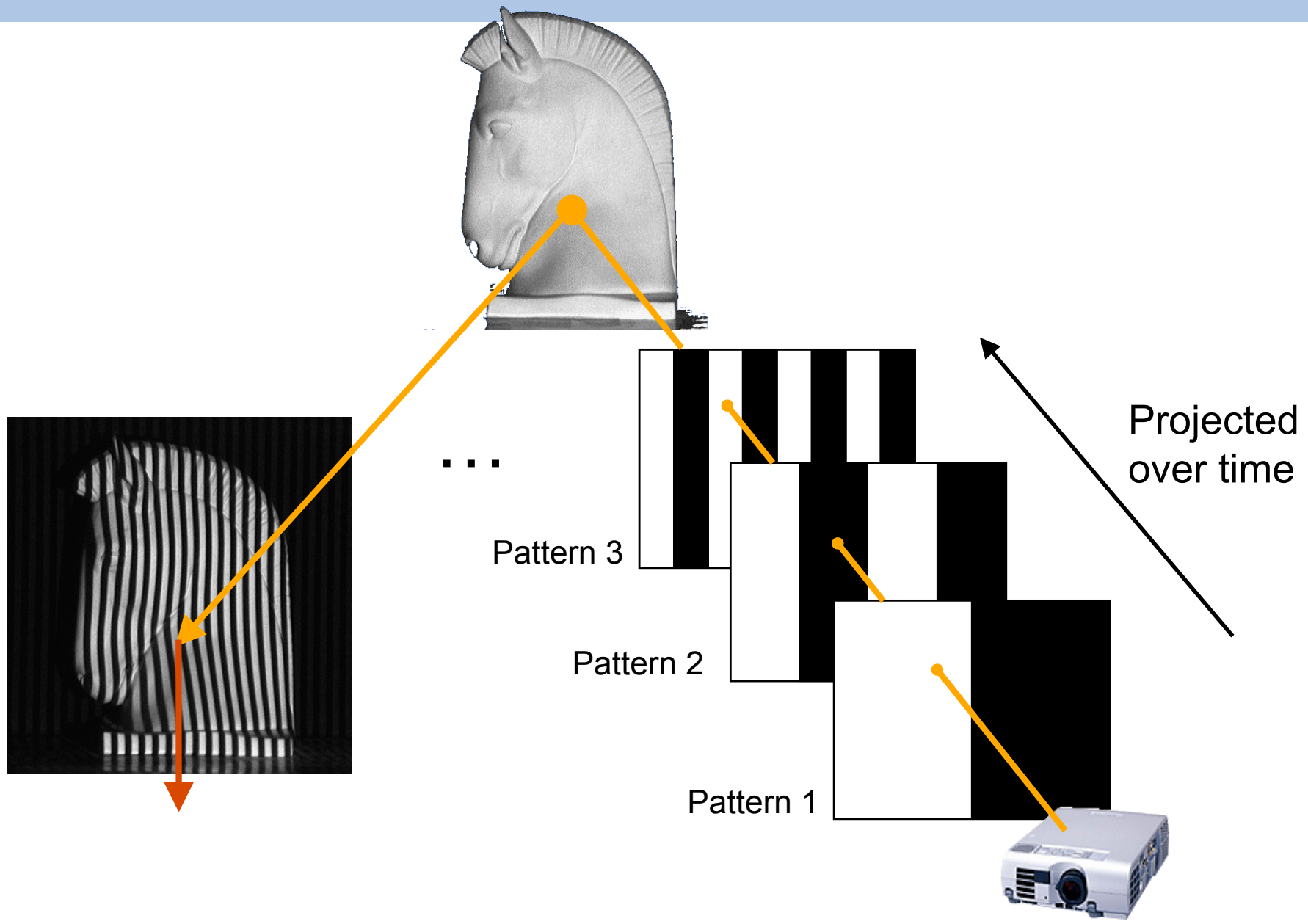


f
n=5, δ=22.5°
X
X→F-[[X]+X]+F[+FX]-X
F→FF





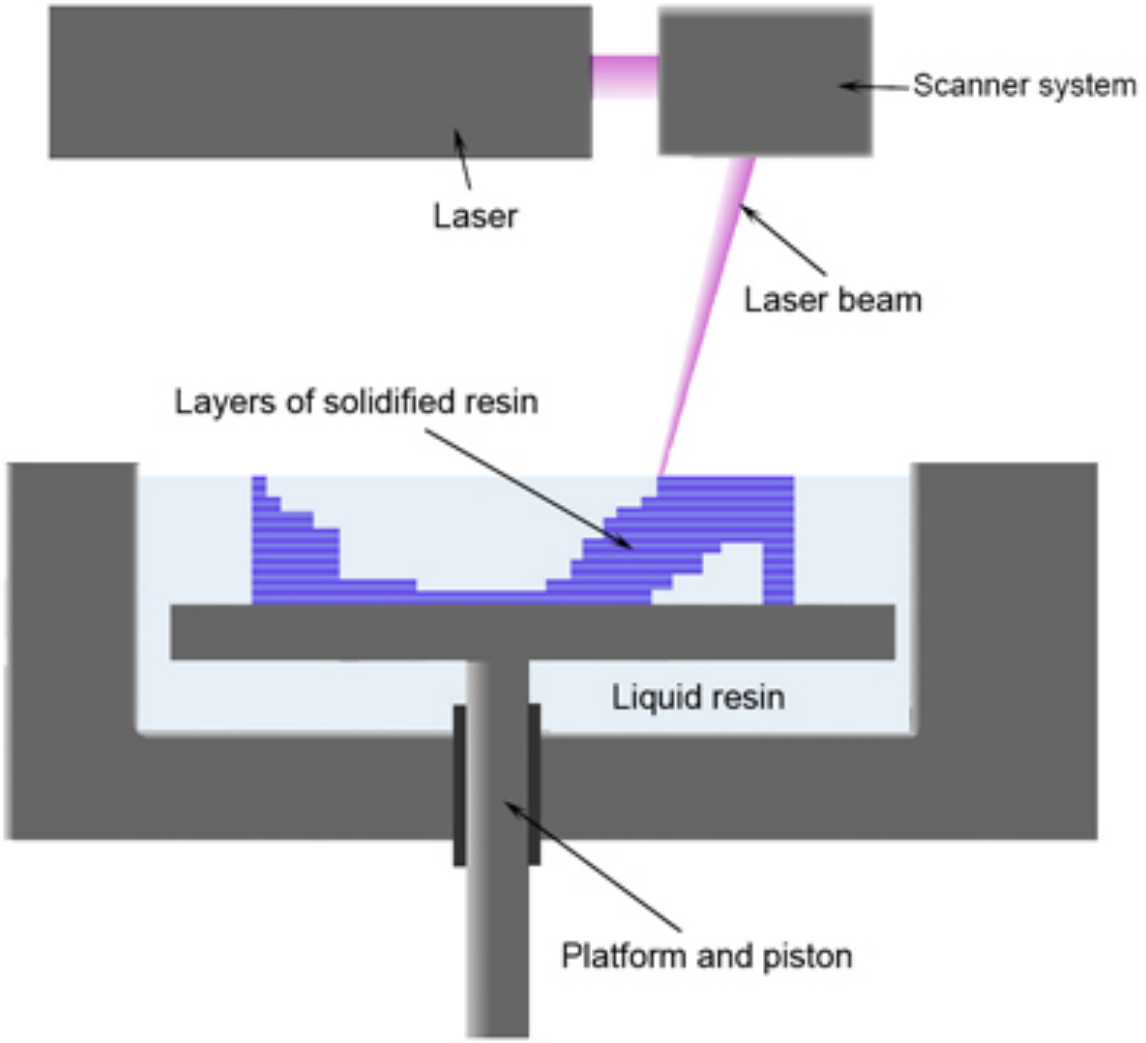
3D Photography / 3D Scanning

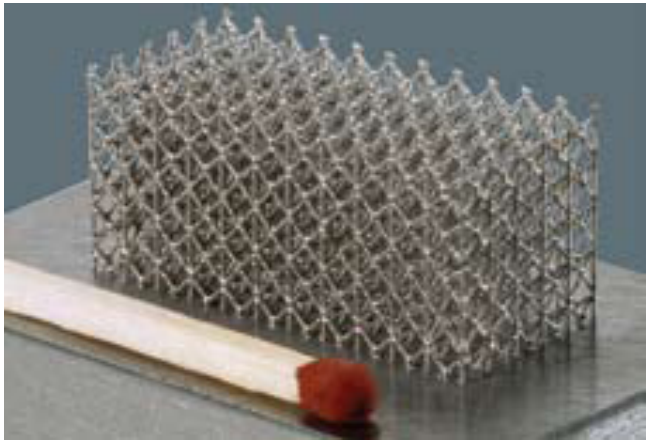


Range Processing Pipeline

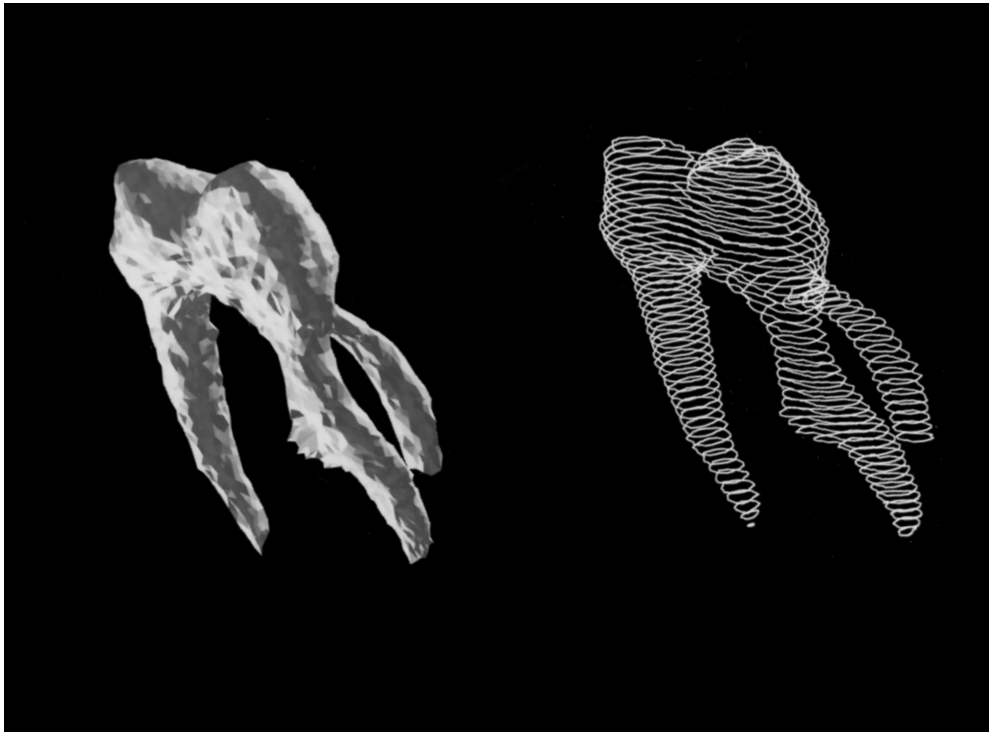
- Generate a mesh from a set of surface samples

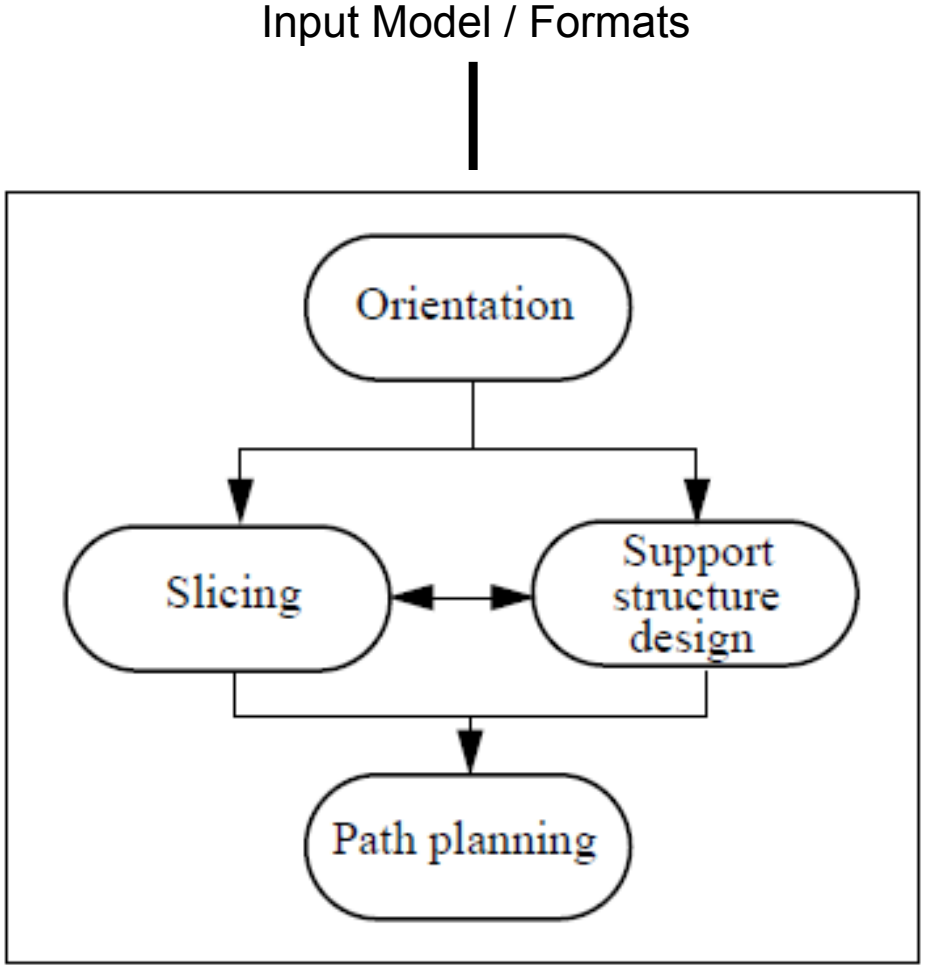
Additive Manufacturing Hardware



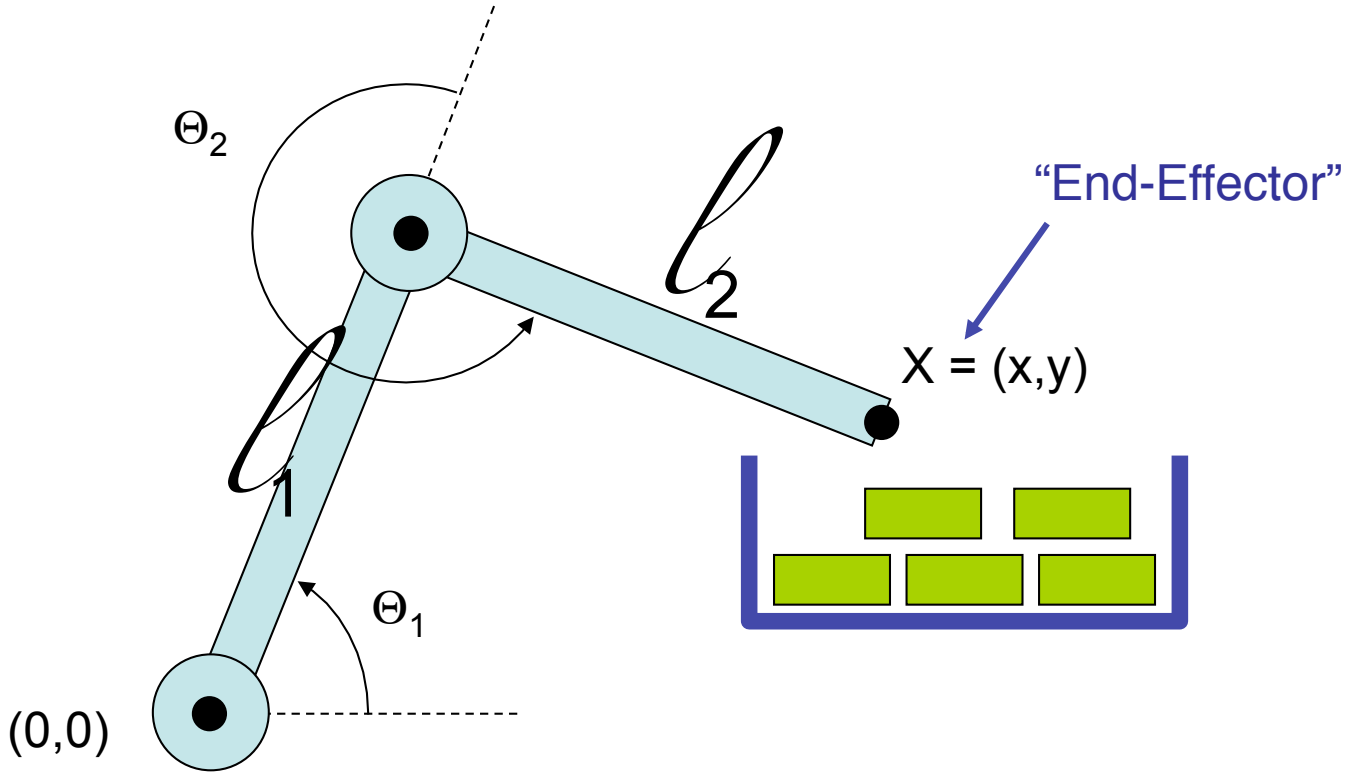


Additive Manufacturing Software





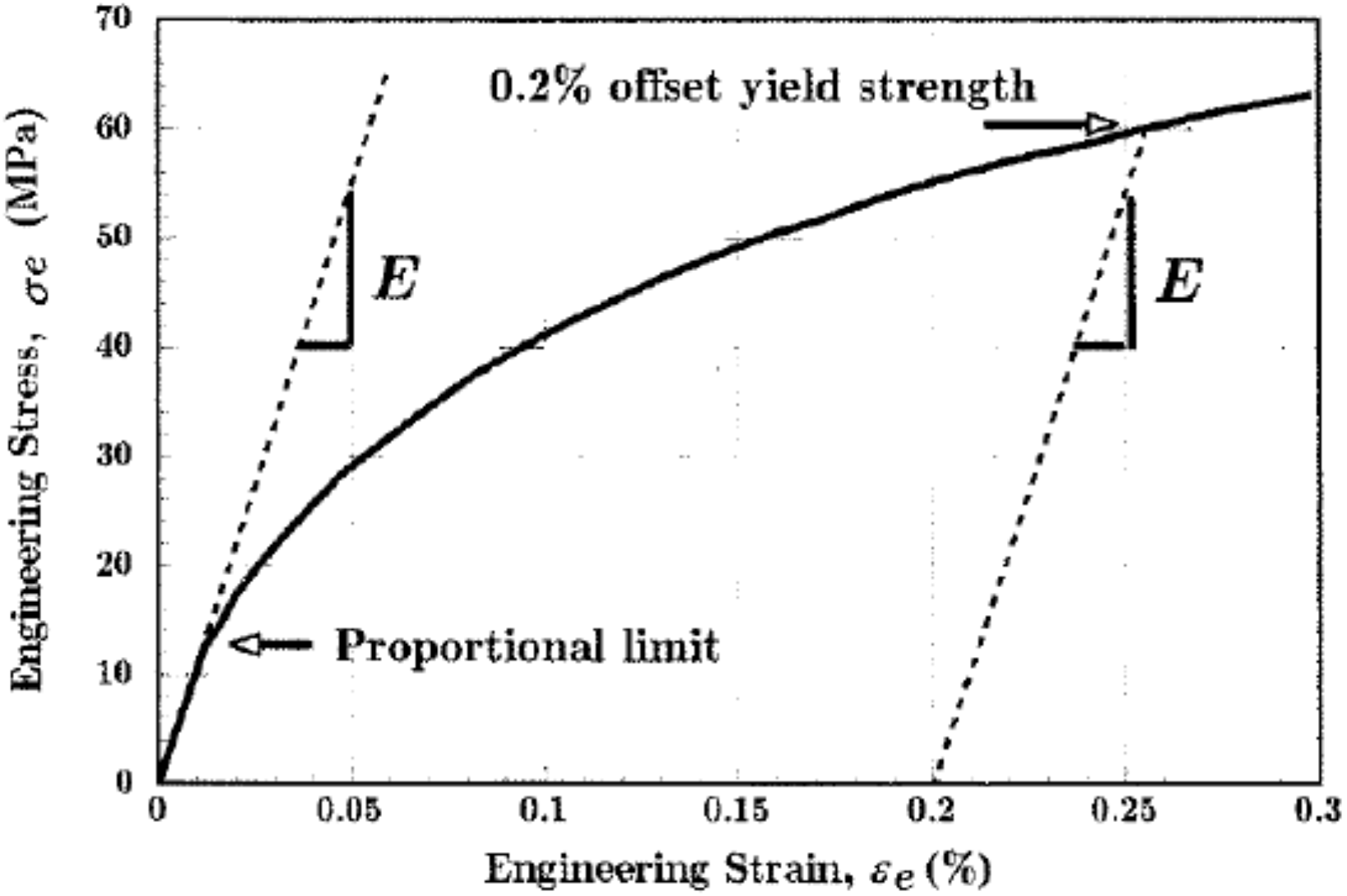
Simulation: Kinematics



Simulation: Dynamics

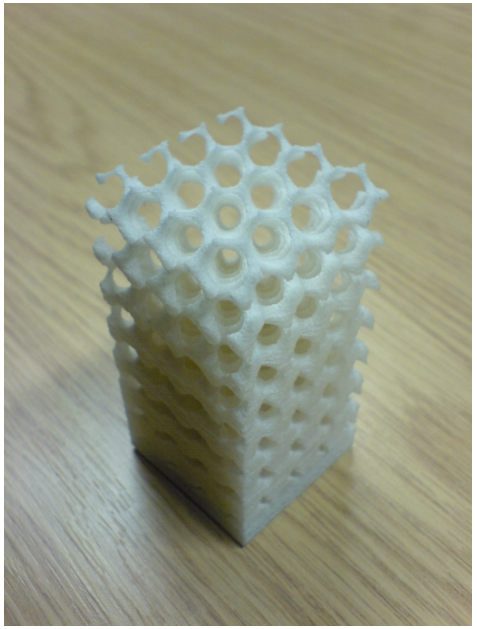
- Finite Element Method

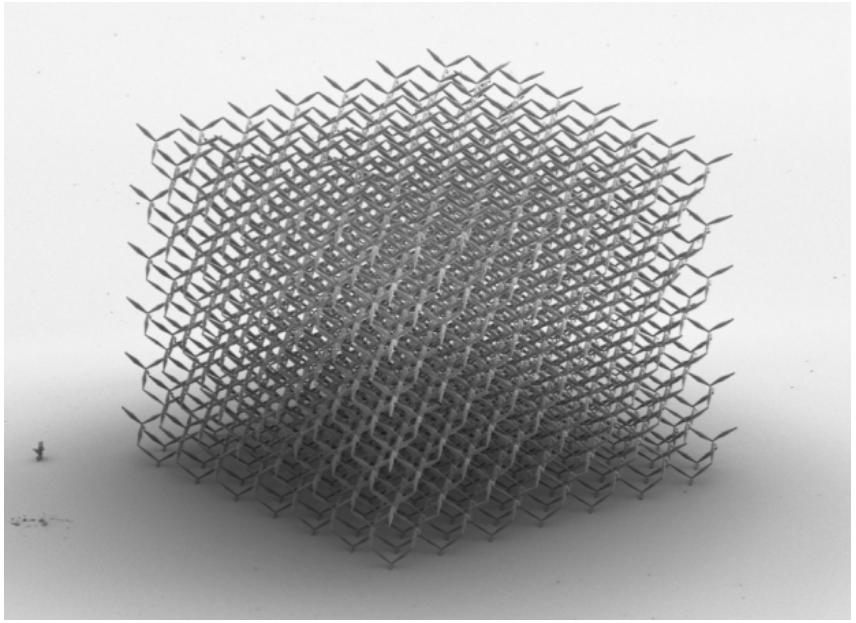
Material Models



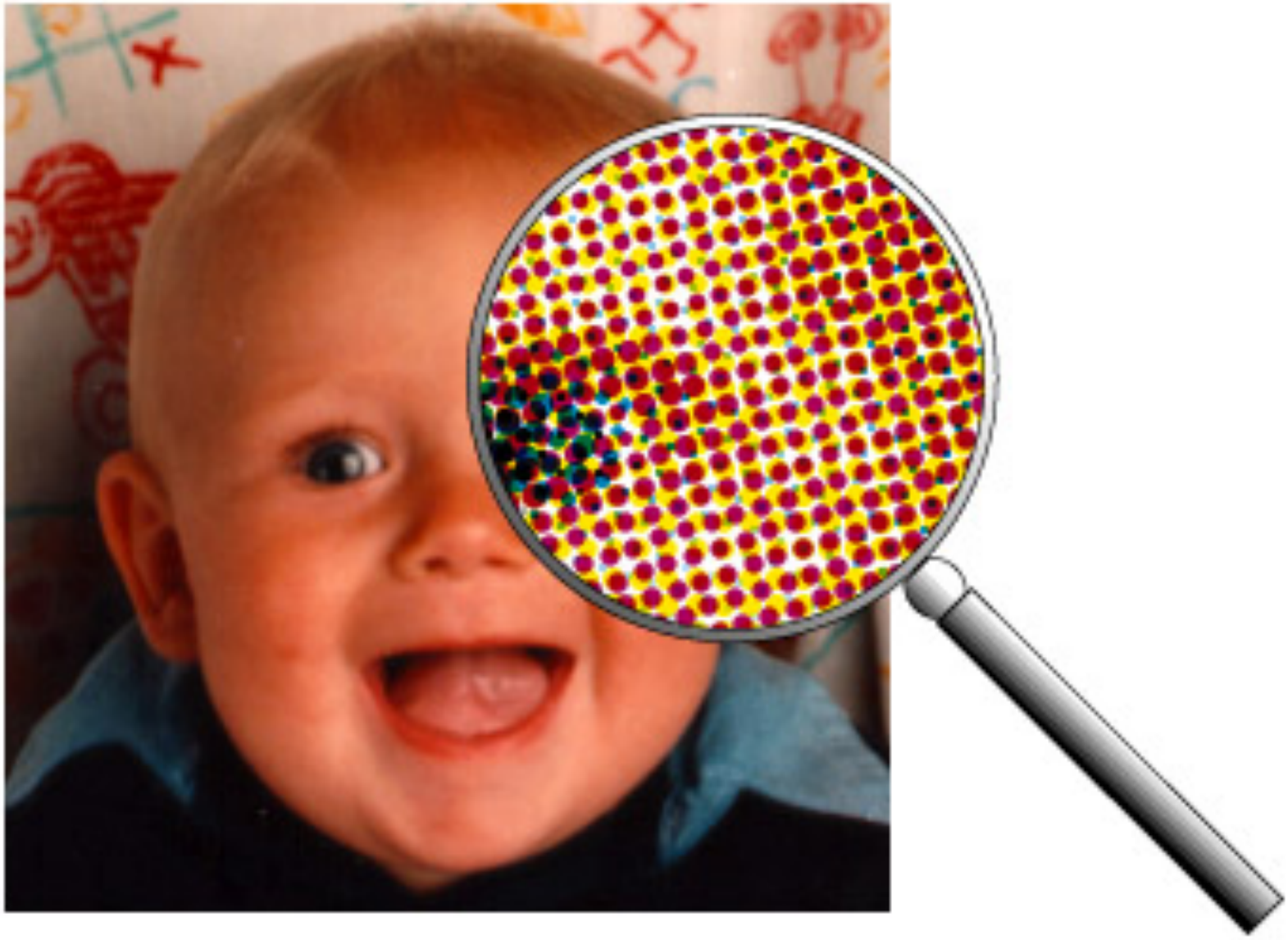
Recess Week

Advanced Materials



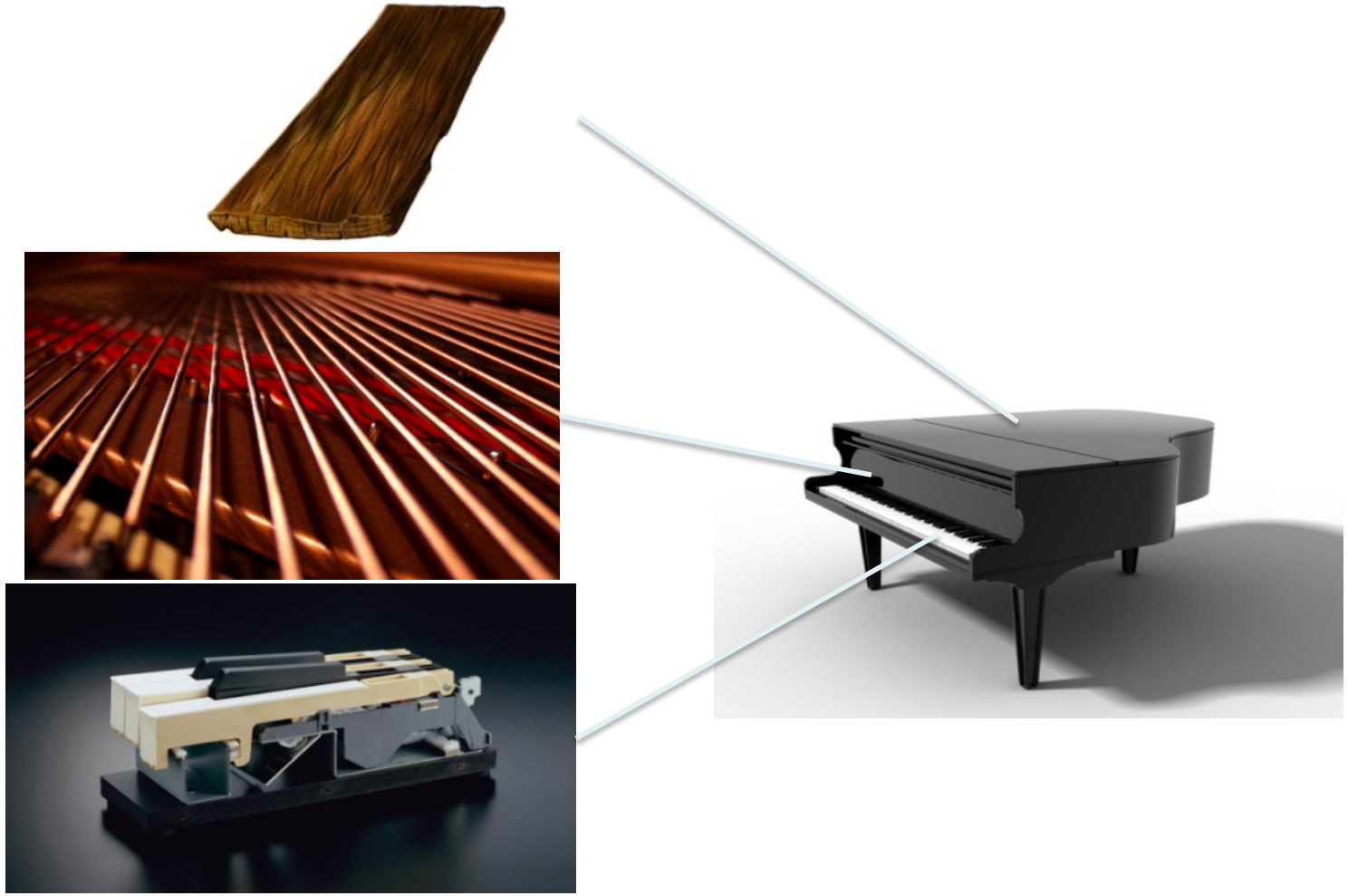


Principles of 2D Printing



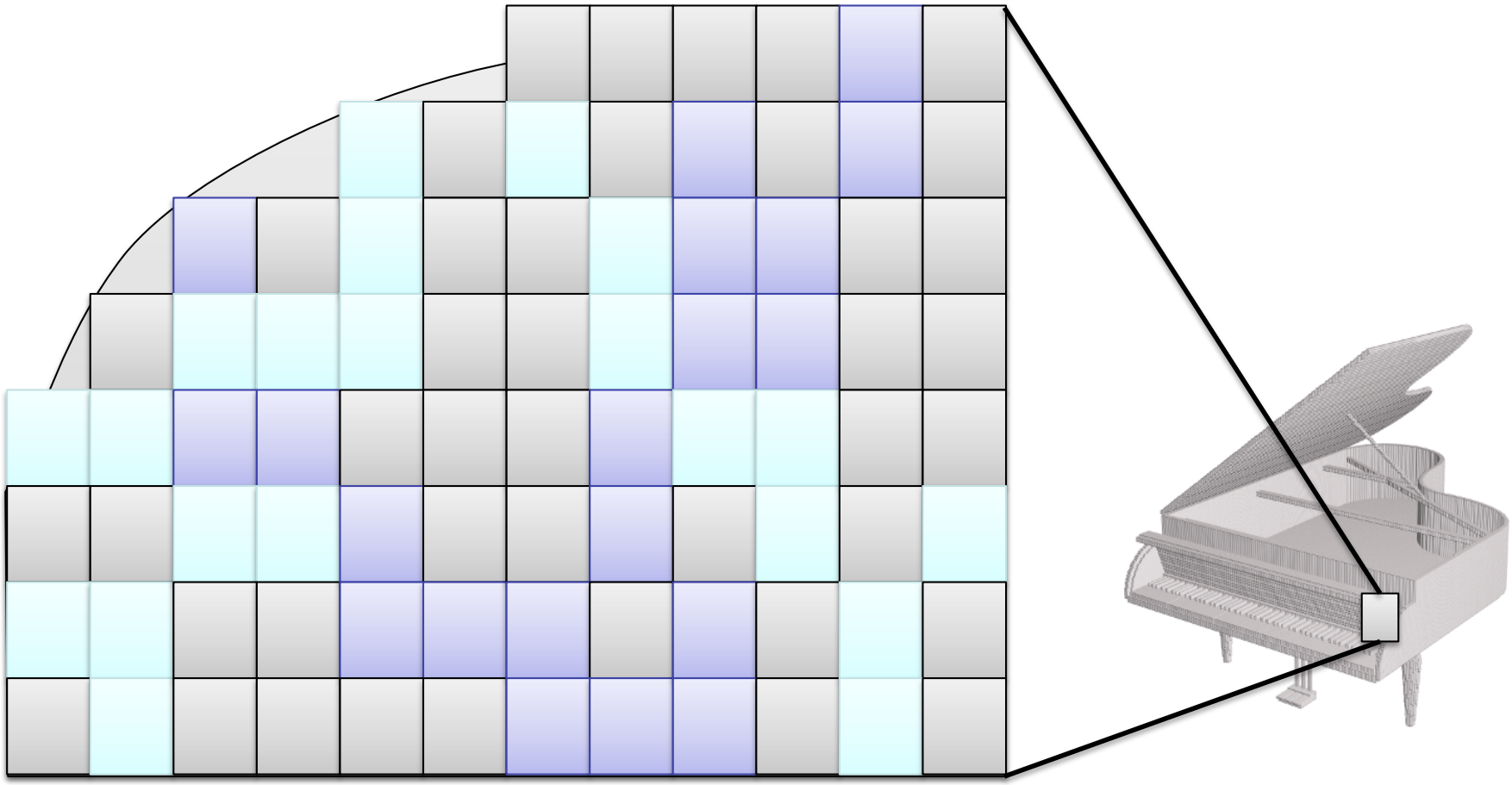
OpenFab: Direct Specification

Vidimce et al., Siggraph 2013



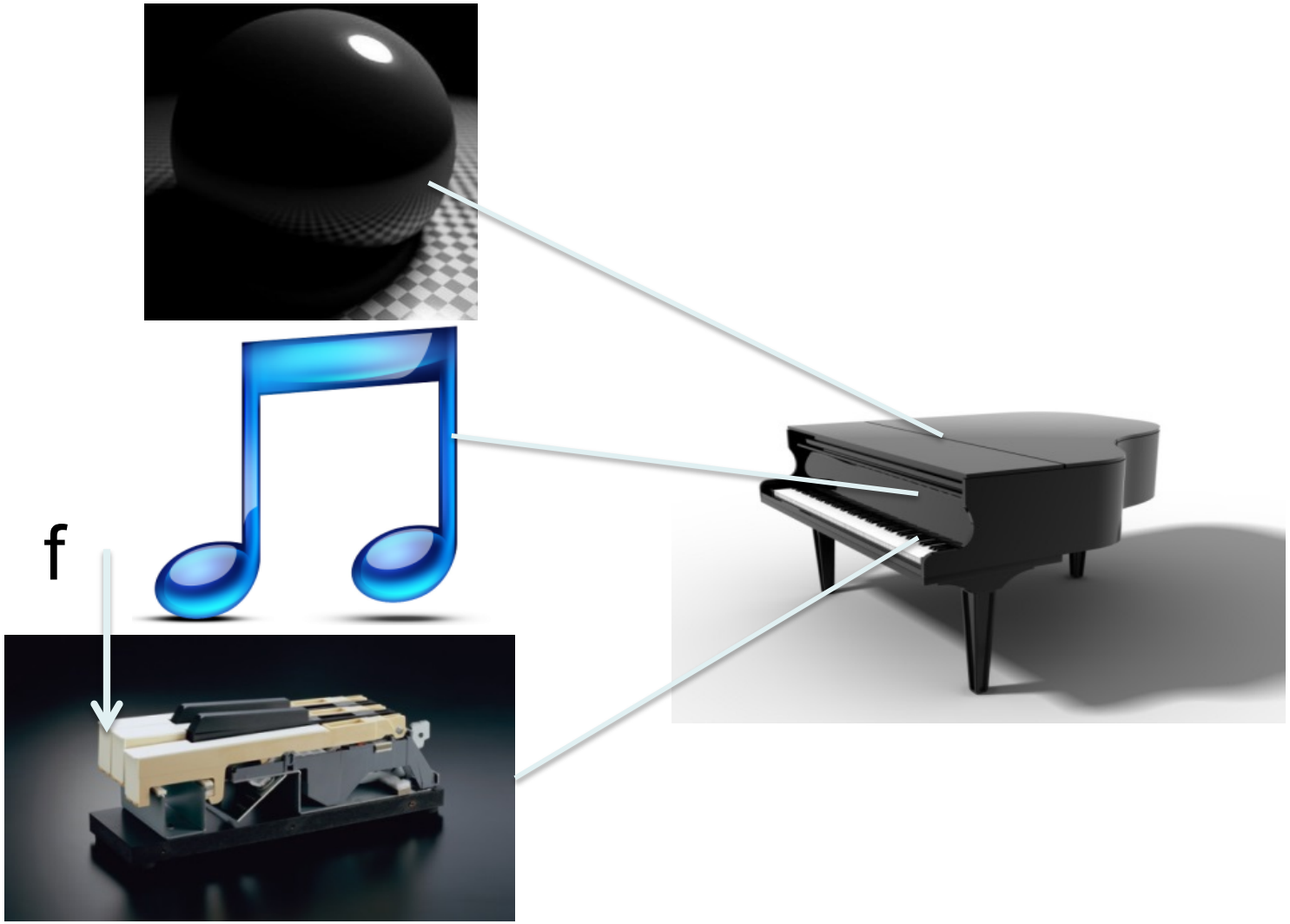
OpenFab: Direct Specification

Vidimce et al., Siggraph 2013

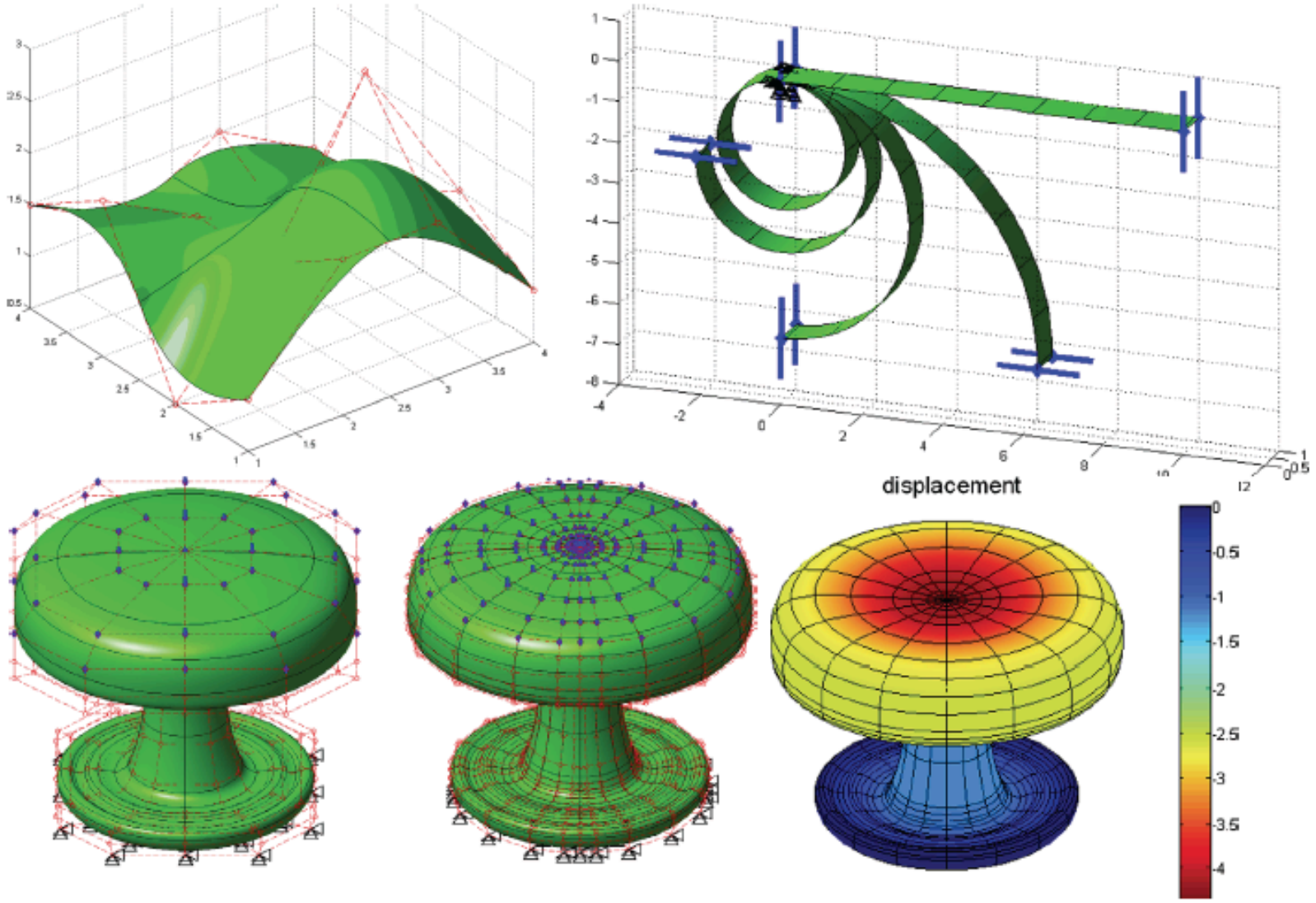


Spec2Fab: Functional Specification

Chen et al., Siggraph 2013

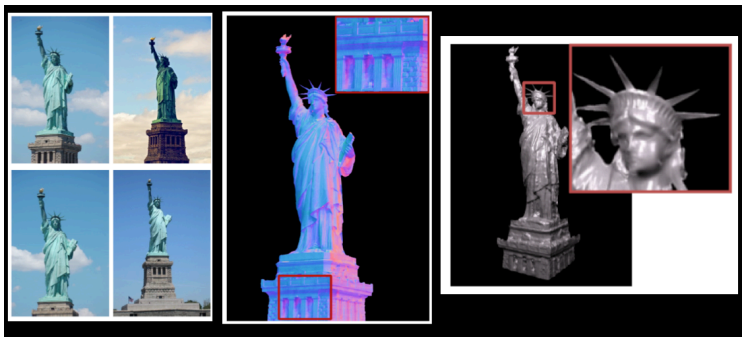


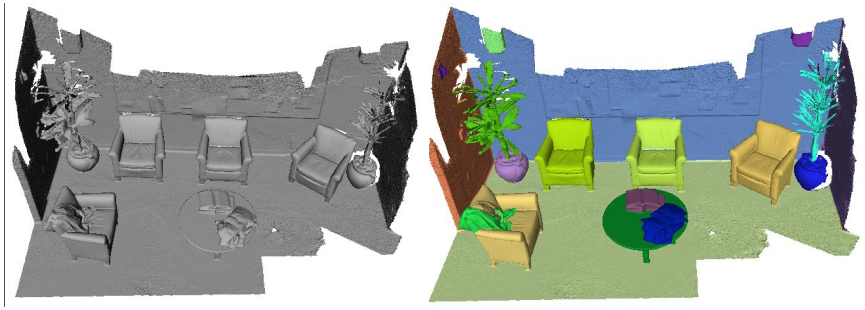
Isogeometric Analysis



Latest Research from SUTD VGD

- Topics:
  - Guided Design Tool
  - Photometric Stereo
  - Machine Learning based Geometry Modeling
  - 3D Models Reconstruction and Understanding
  - Physics-aware Design Tool



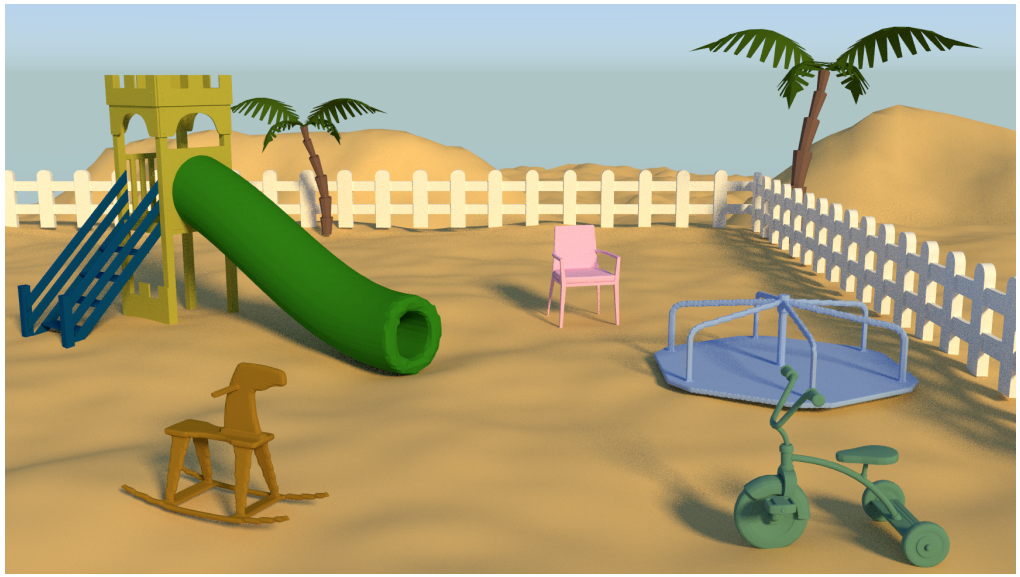


Overview of the Semester

- Learning the basics (till the recess week)
  - Solid Modeling
  - 3D Scanning
  - 2D & 3D Printing
  - Simulation
  - Optimization
- Case studies (after the recess week)

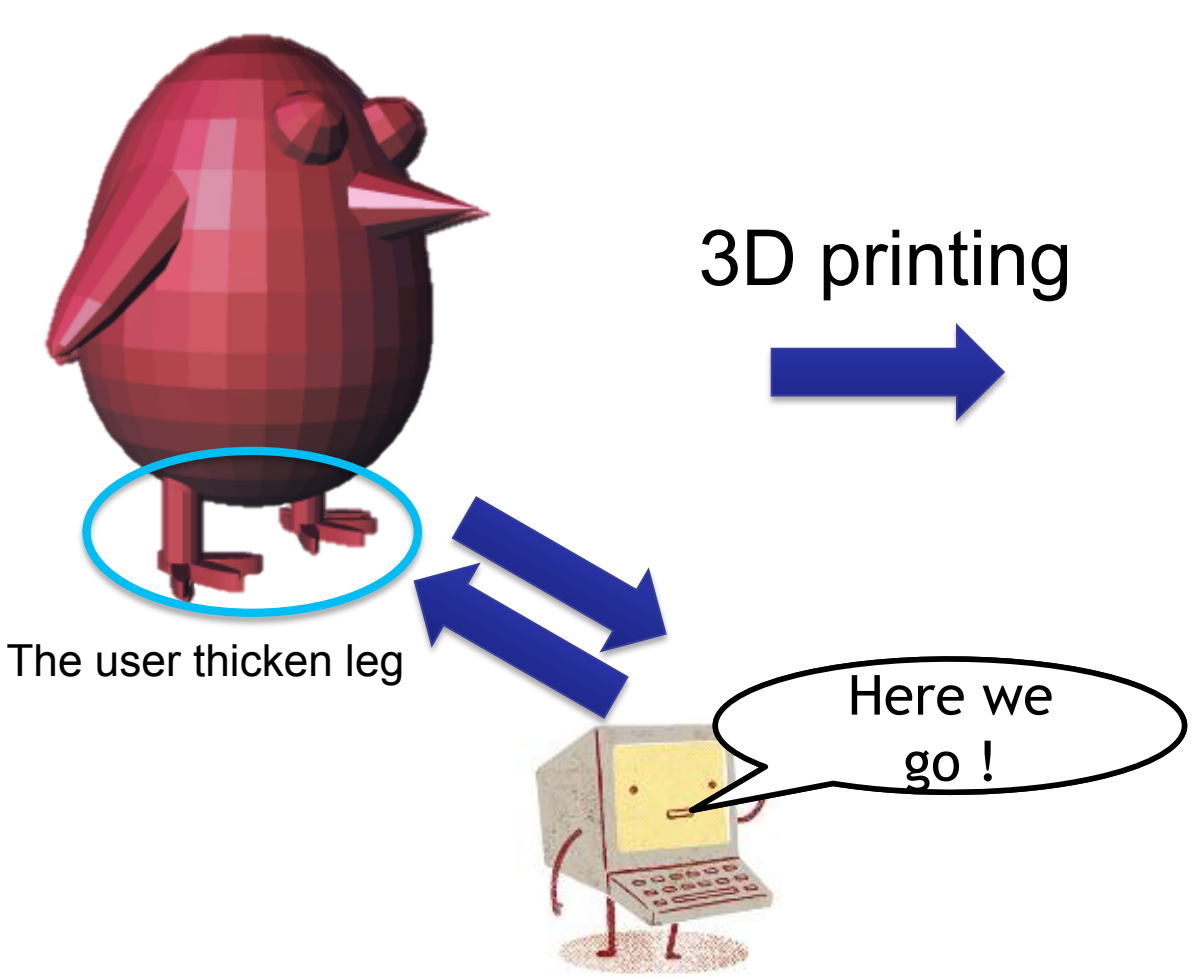
Zoomorphic Design

Duncan et al., Siggraph 2015

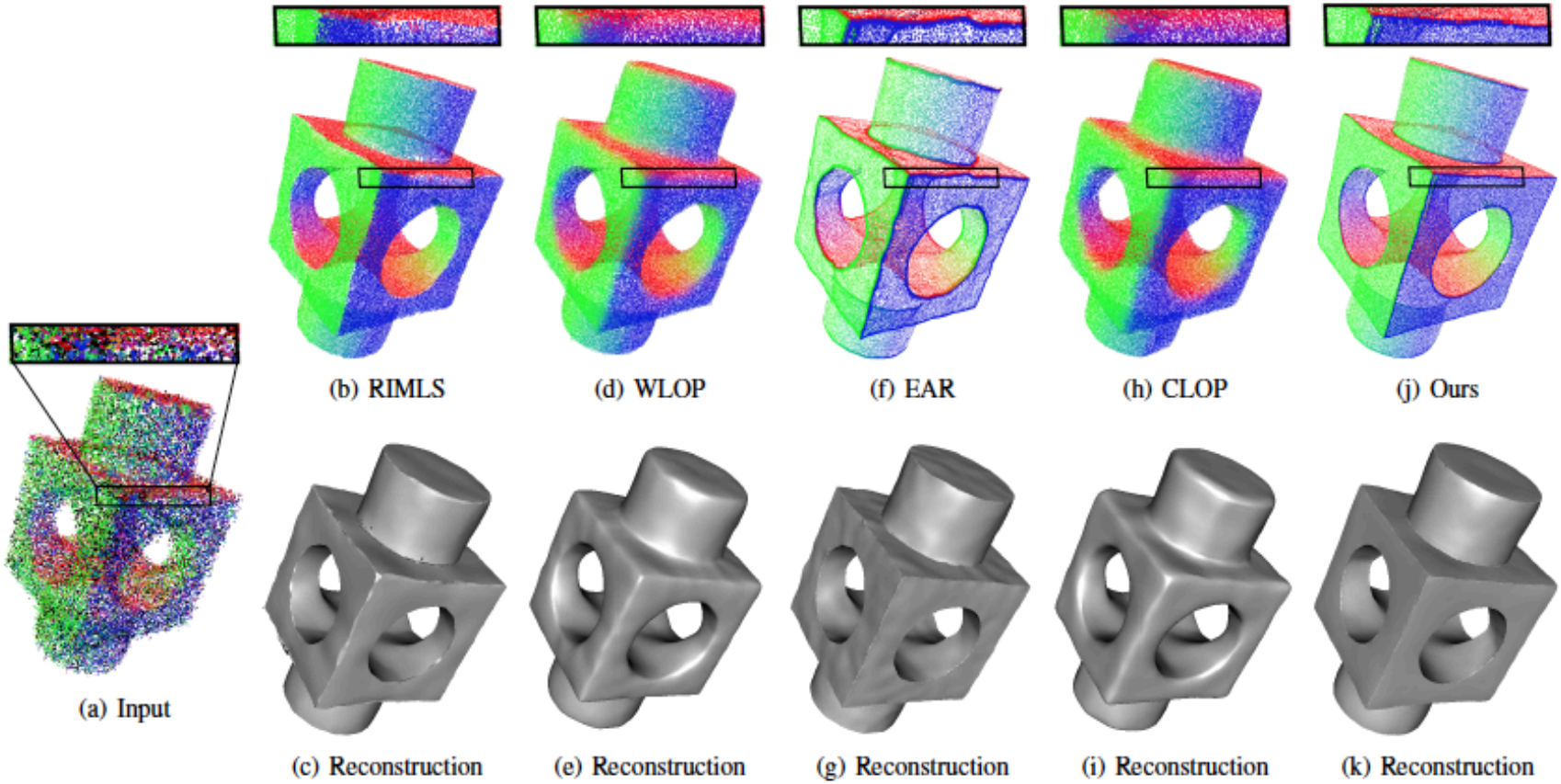


Structural Analysis for 3D Printing

Umetani and Schmidt Siggraph Asia 2013

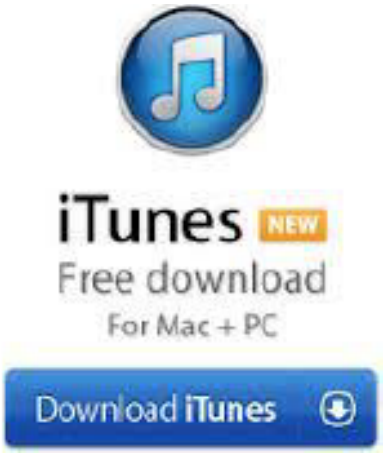


Geometry Denoising



Open Problems in Computational Fabrication

- Scale & resolution
- Computational complexity
- Materials
- User interfaces
- Copyrights



Overview of Latest Research

- Latest papers on computational fabrication to be presented at ACM SIGGRAPH/SIGGRAPHAsia Eurographics, CHI, UIST

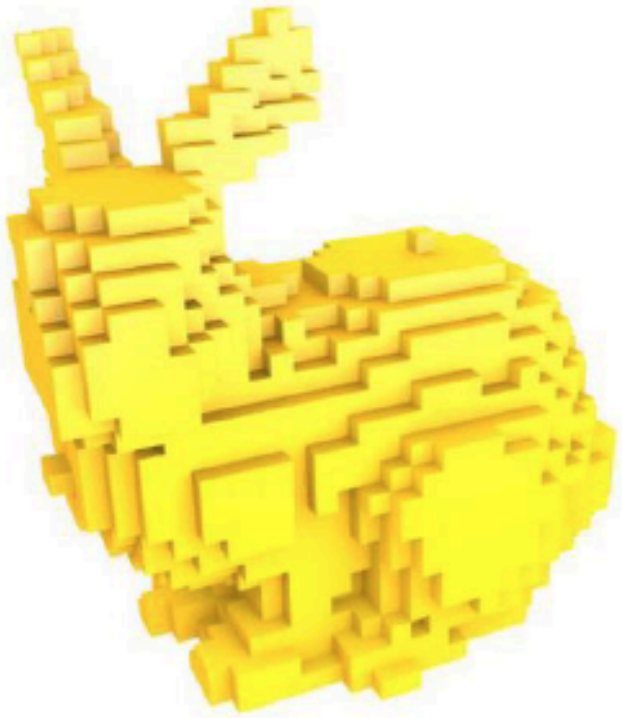
Questions?

Plan

- Overview of computational fabrication
- Administrivia
- Overview of the semester
- **Overview of the assignments**
- Overview of the labs
- Sample projects

Assignment 1: Voxelization

- Convert a surface (e.g., a mesh) into a volumetric model (C++)

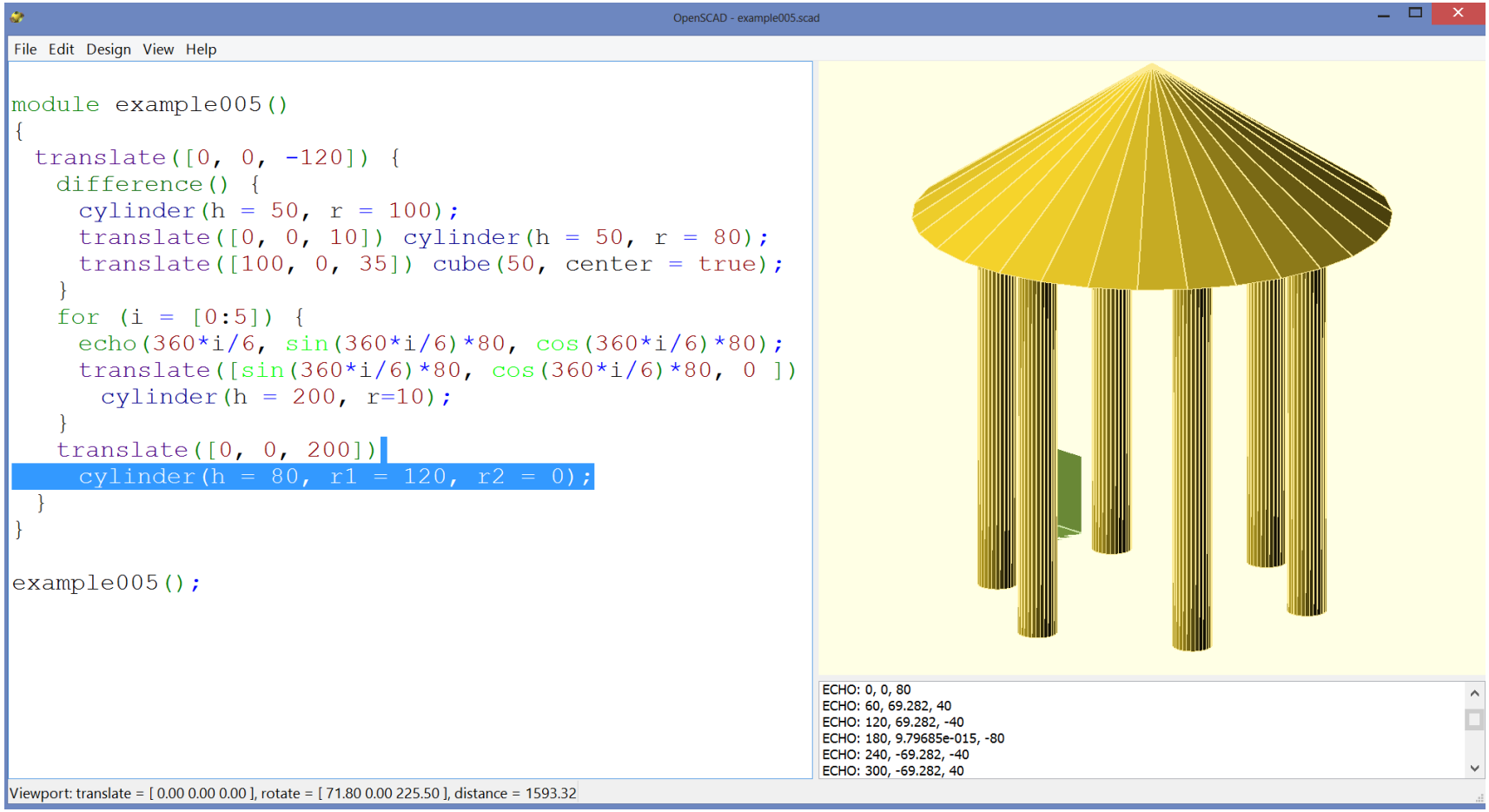


Bunny 32x32x32

Bunny 64x64x64

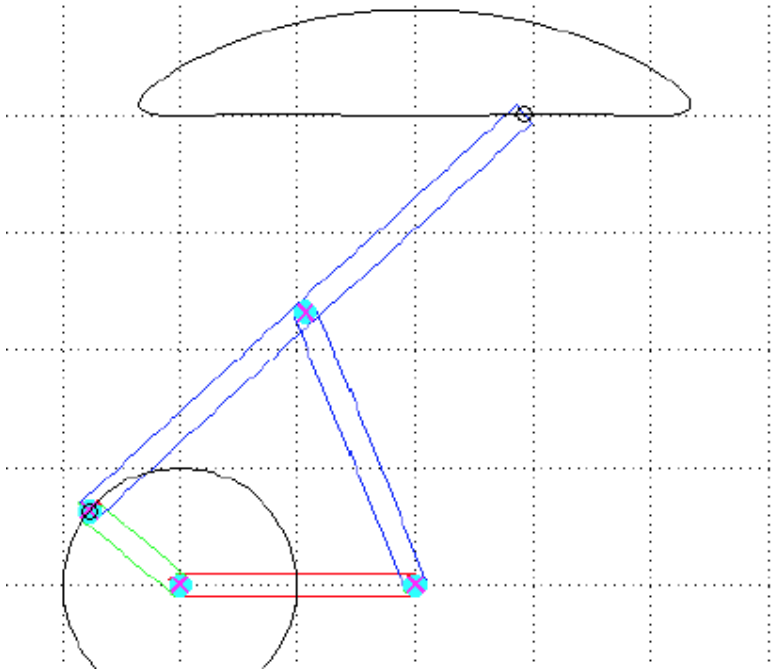
Assignment 2: Procedural Geometry

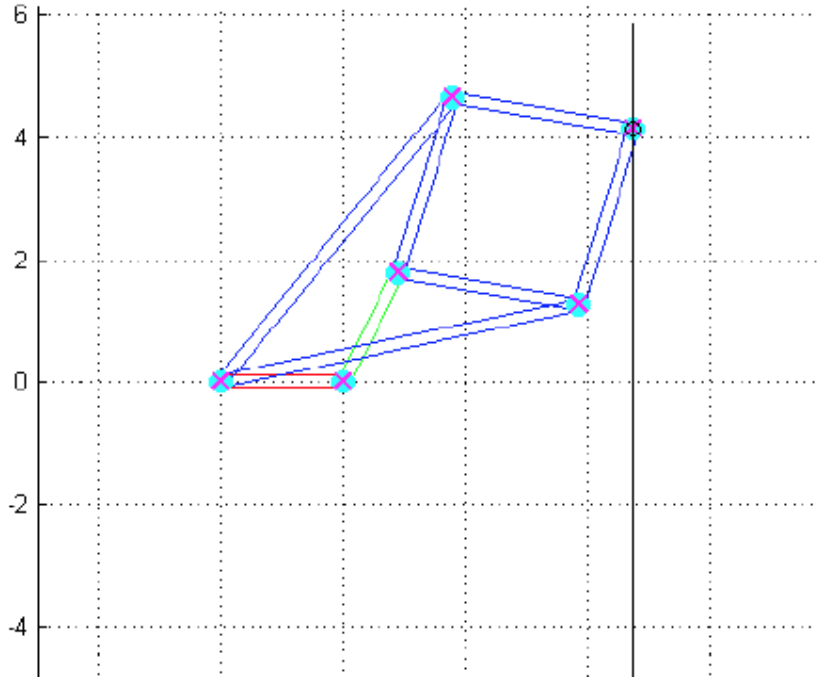
- Design a parameterized model using OpenSCAD



Assignment 3: Kinematics

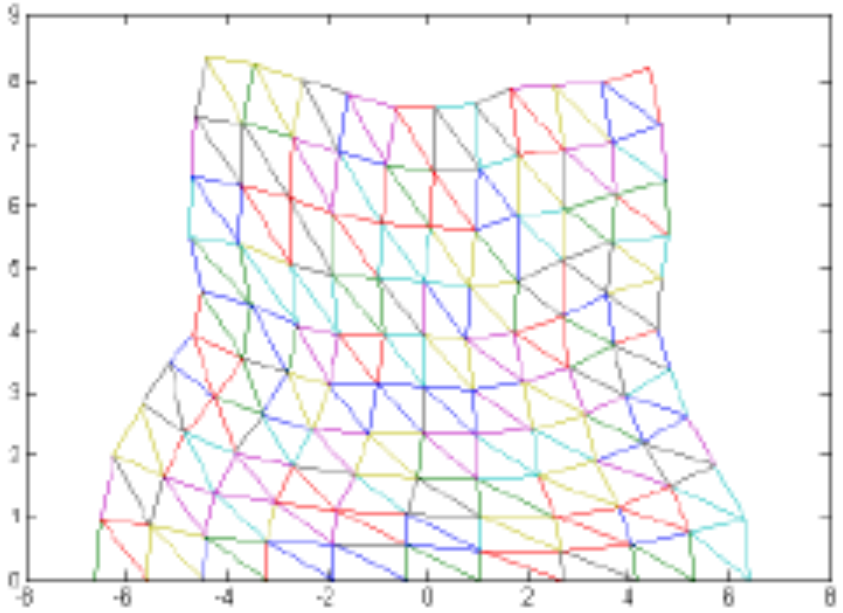
- Computational linkage design in Matlab



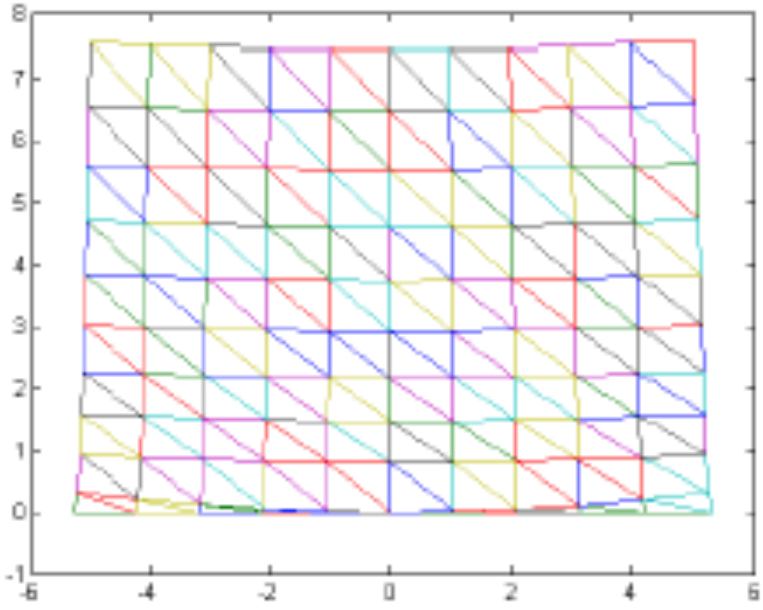


Assignment 4: Finite Element Method

- 2D FEM simulation in Matlab



10x10 Neohookean



10x10 Kirchoff

Plan

- Overview of computational fabrication
- Administrivia
- Overview of the semester
- Overview of the assignments
- **Overview of the labs**
- Sample projects

Labs

1: 3D scanning (May 23th)

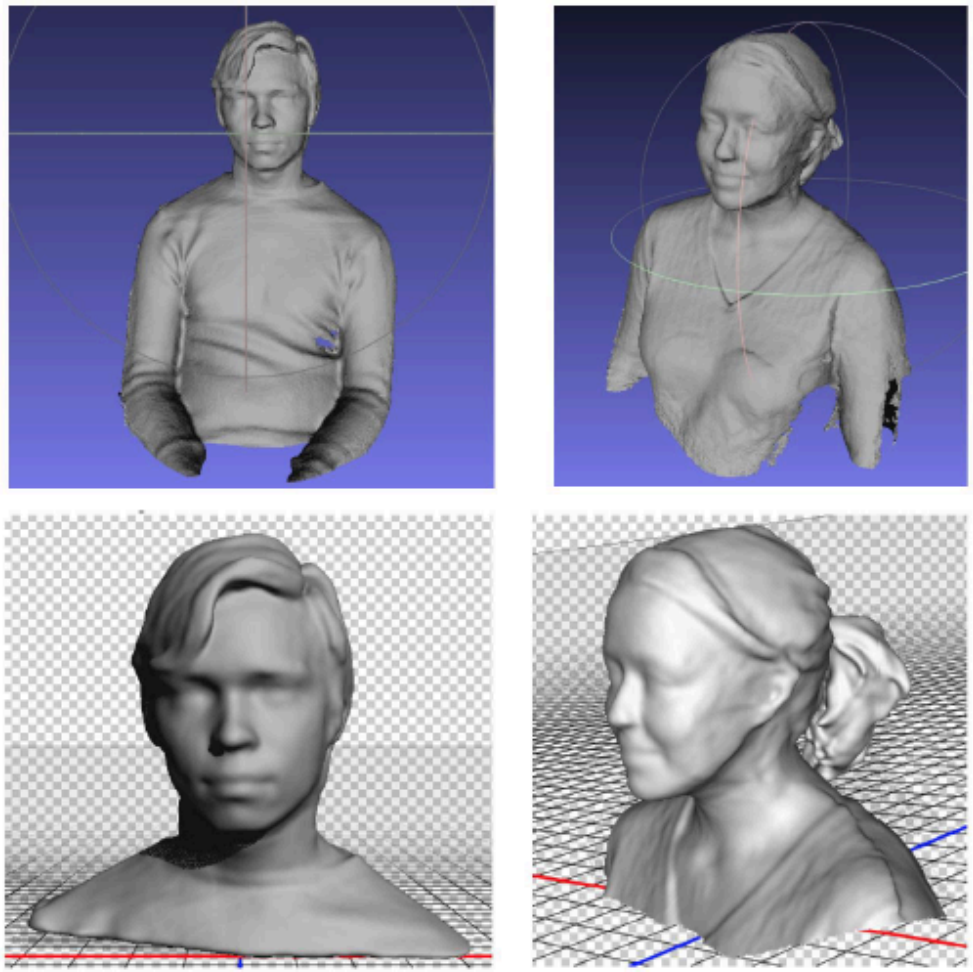
2: Basic 3D printing (June 6th)

3: Linkage fabrication (June 13th)

4: 3D printing and testing of flexures (June 27th and July 4th)

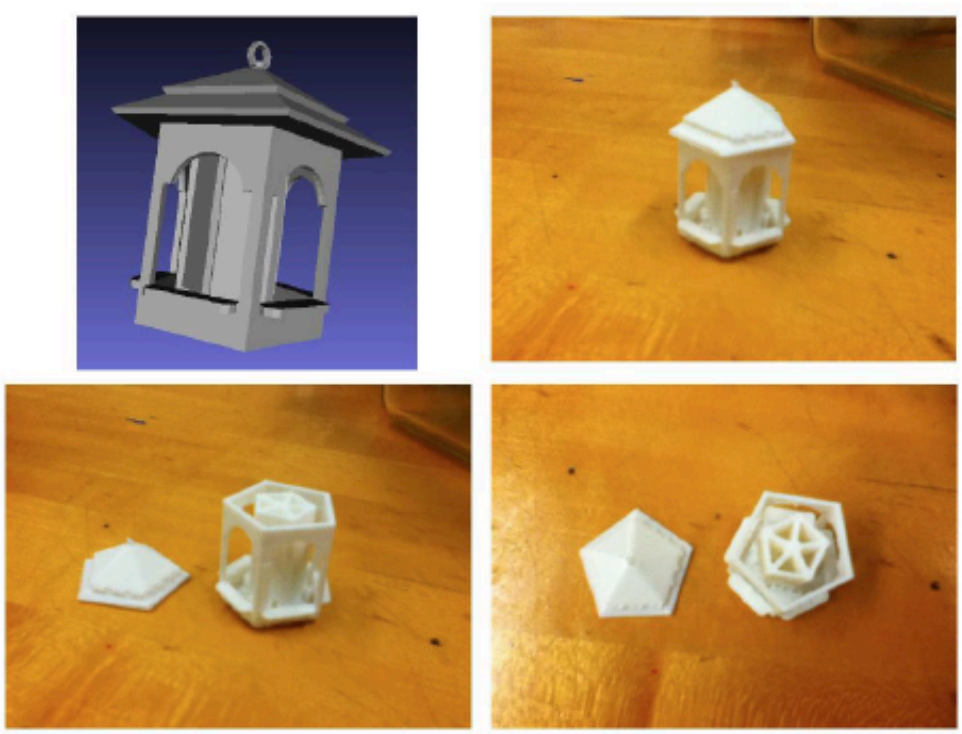
Lab 1: 3D Scanning

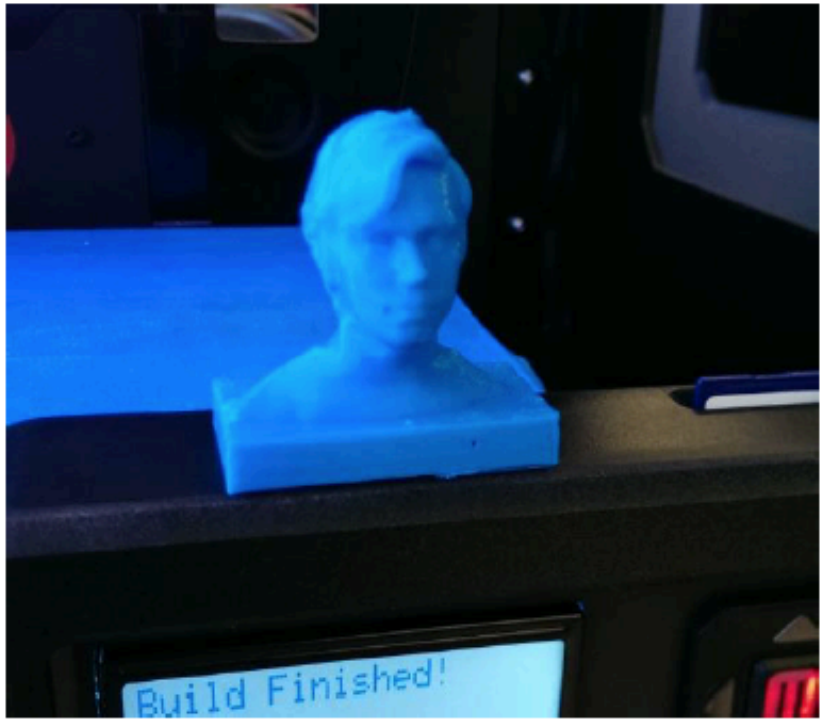
- Use MS Kinect to scan a 3D object



Lab 2: Basic 3D Printing

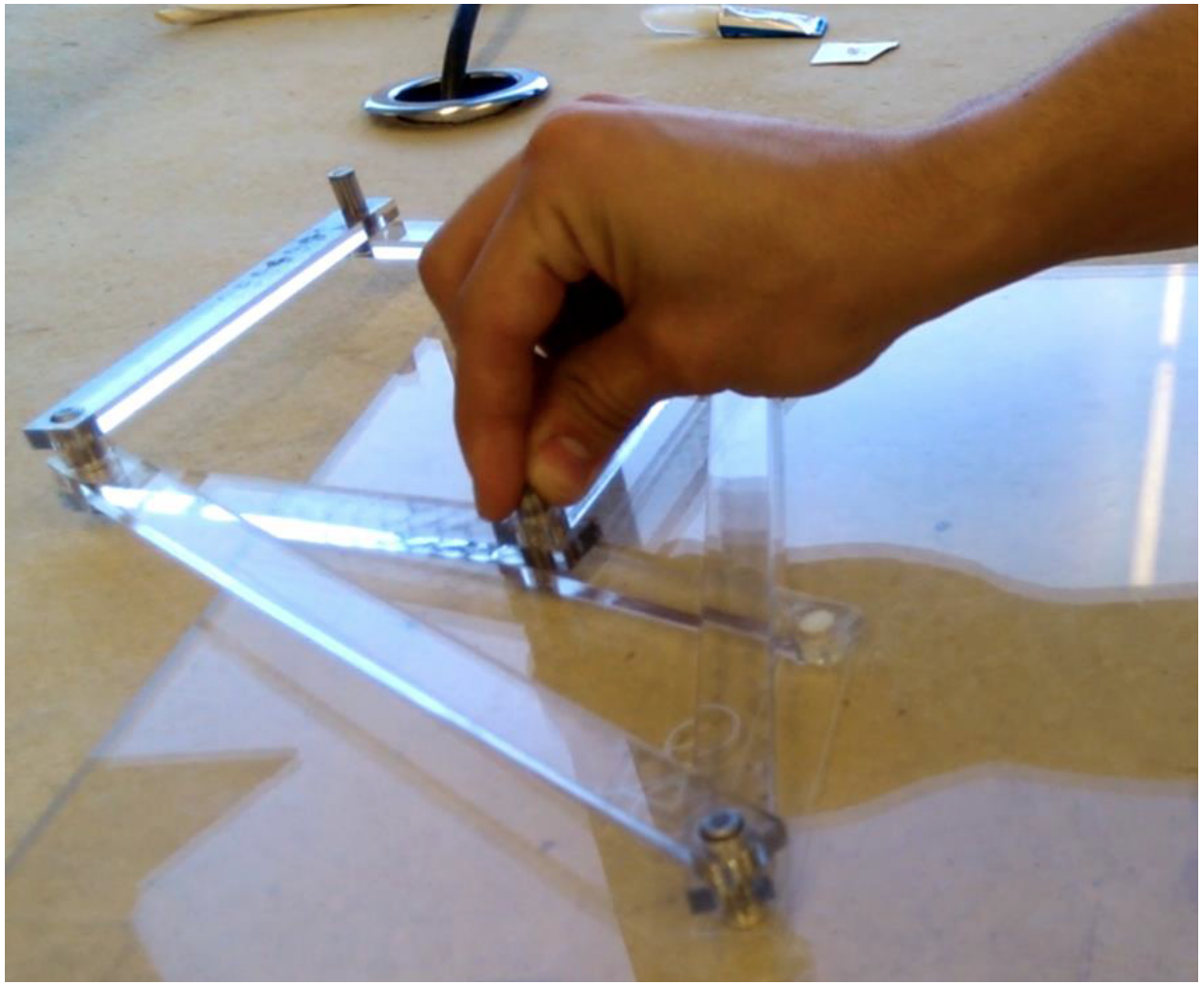
- Print a procedurally-generated object and a 3D scanned object





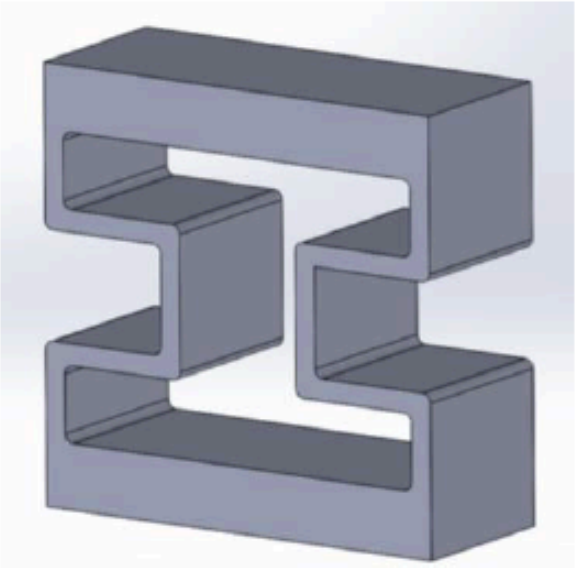
Lab 3: Linkage Design and Fabrication

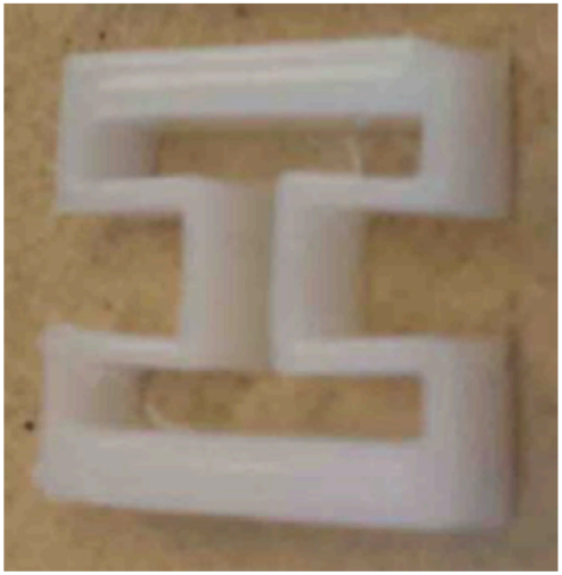
- Design and laser cut a linkage



Lab 4: 3D Printing and Measuring of Flexures

- 3D print flexures and measure their stress-strain curve





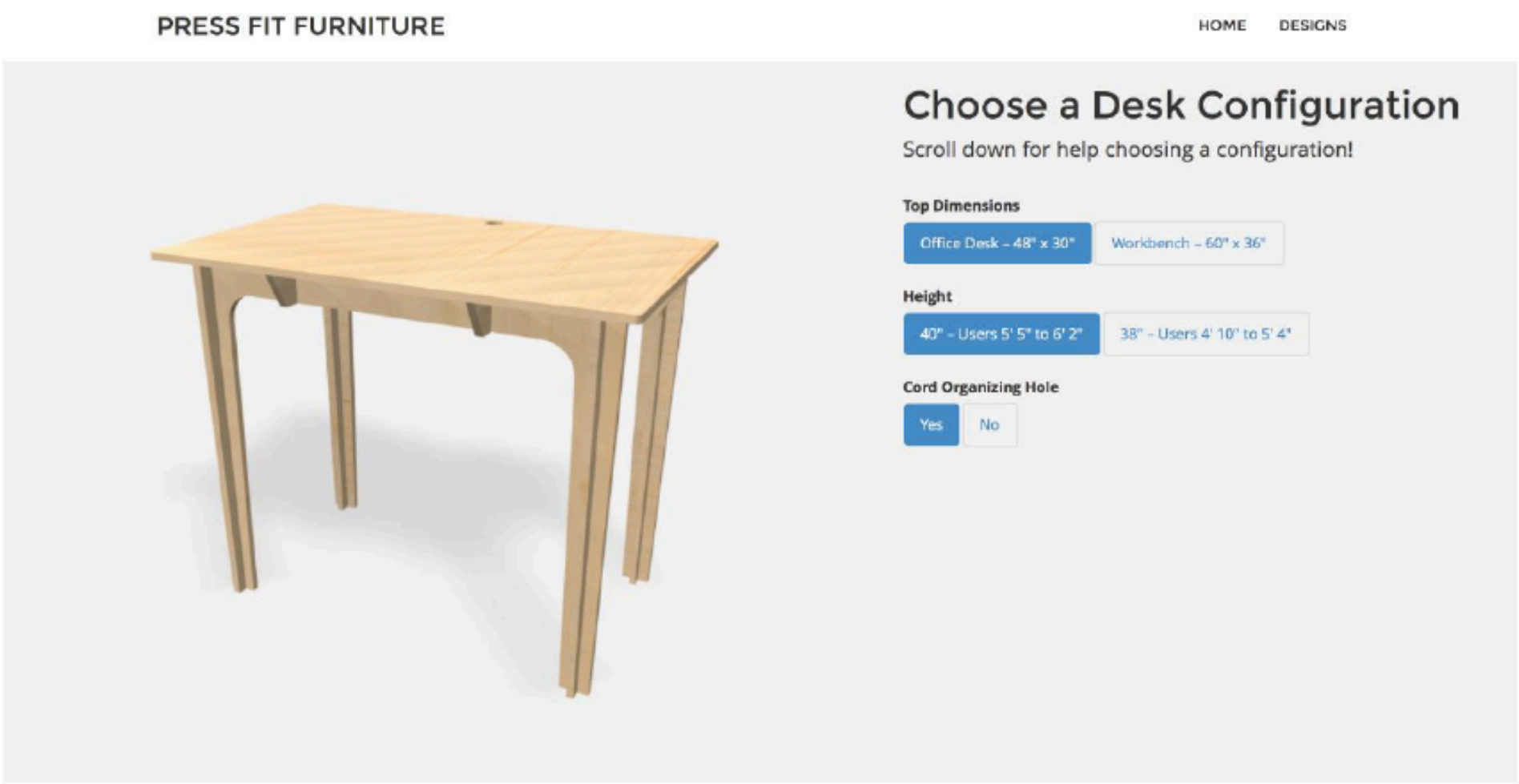
Plan

- Overview of computational fabrication
- Administrivia
- Overview of the semester
- Overview of the assignments
- Overview of the labs
- **Sample projects**

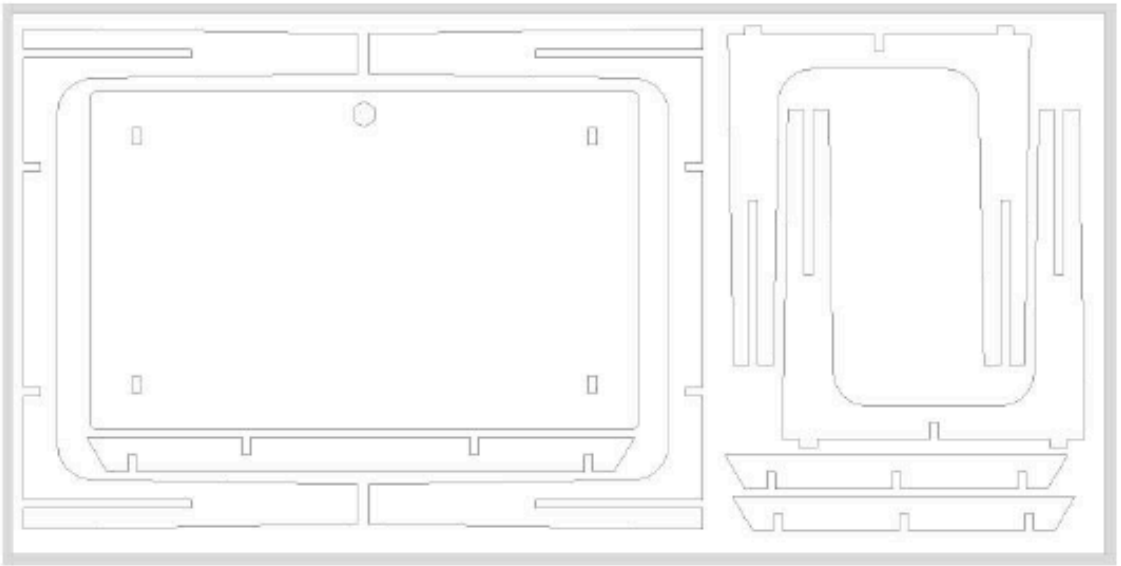
Sample Projects

- **Sample projects from MIT and SUTD**

Sample Projects: Parametric Furniture Design

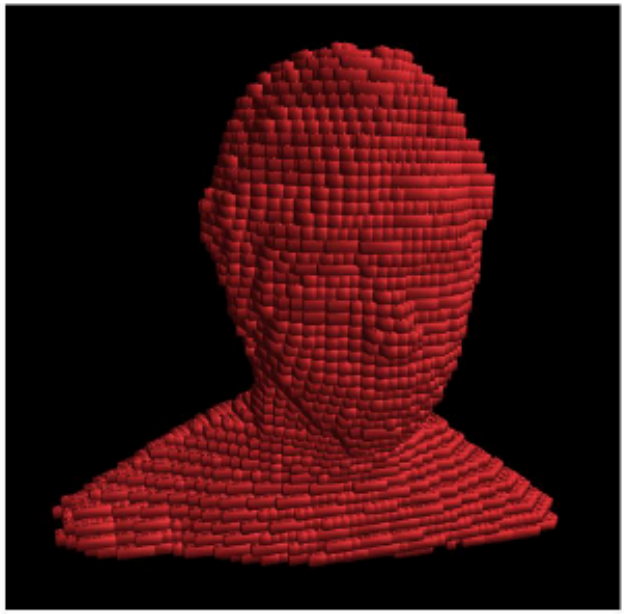


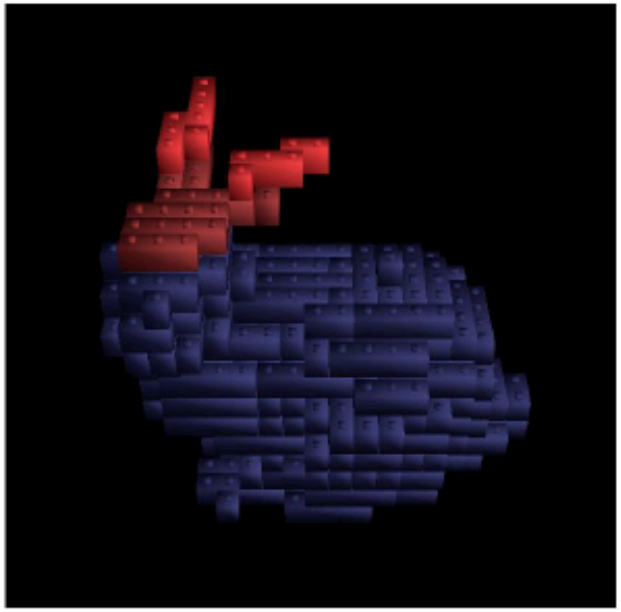
Sample Projects: Parametric Furniture Design



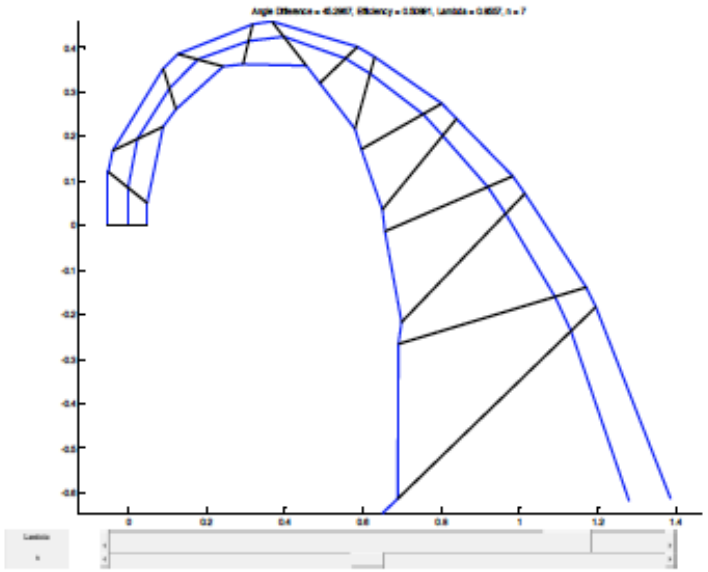
Sample Projects: Parametric Furniture Design

Sample Projects: Legolizer





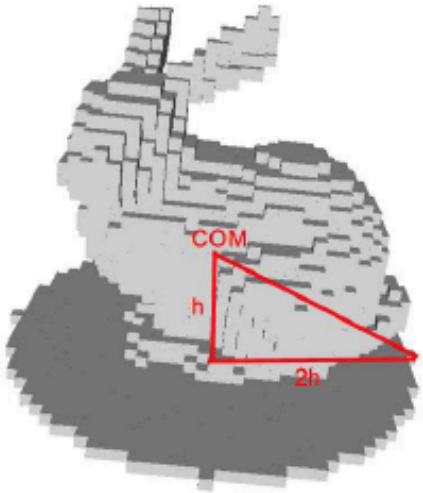
Sample Projects: Laser Cutting Optics for Spectroscopy



Sample Projects: Computational Design of Stable Platforms

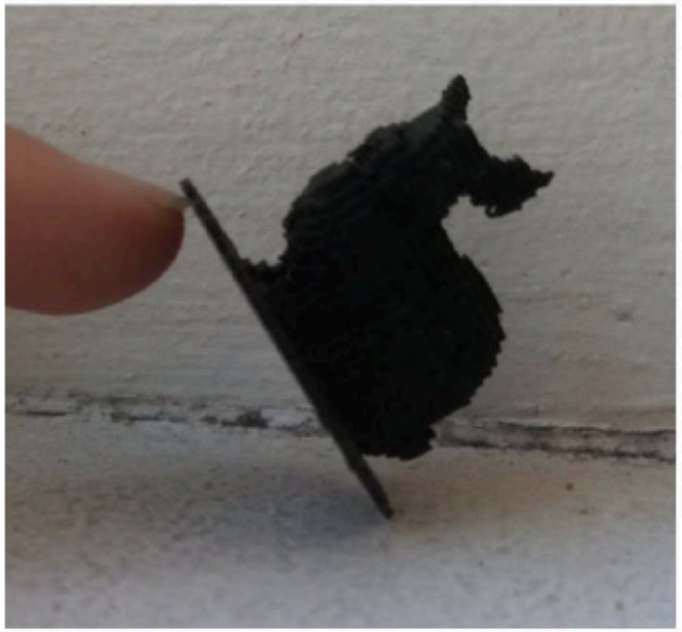
Tolerance = 1

Max Angle = 45°

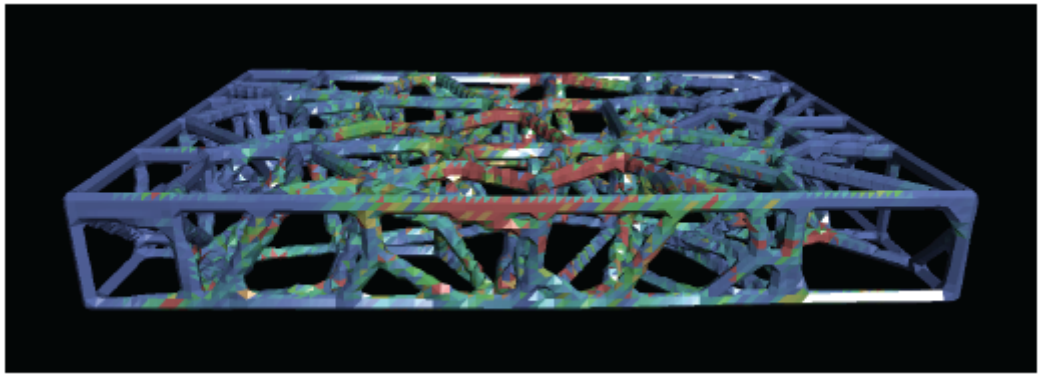


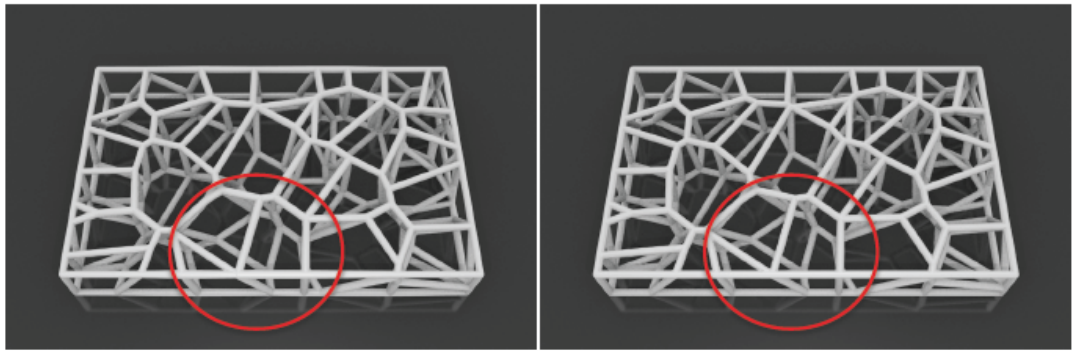
Tolerance = 2

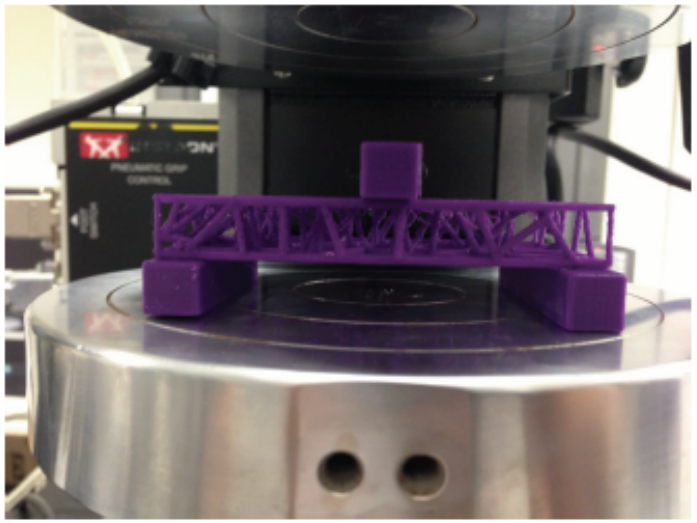
Max Angle = 63°



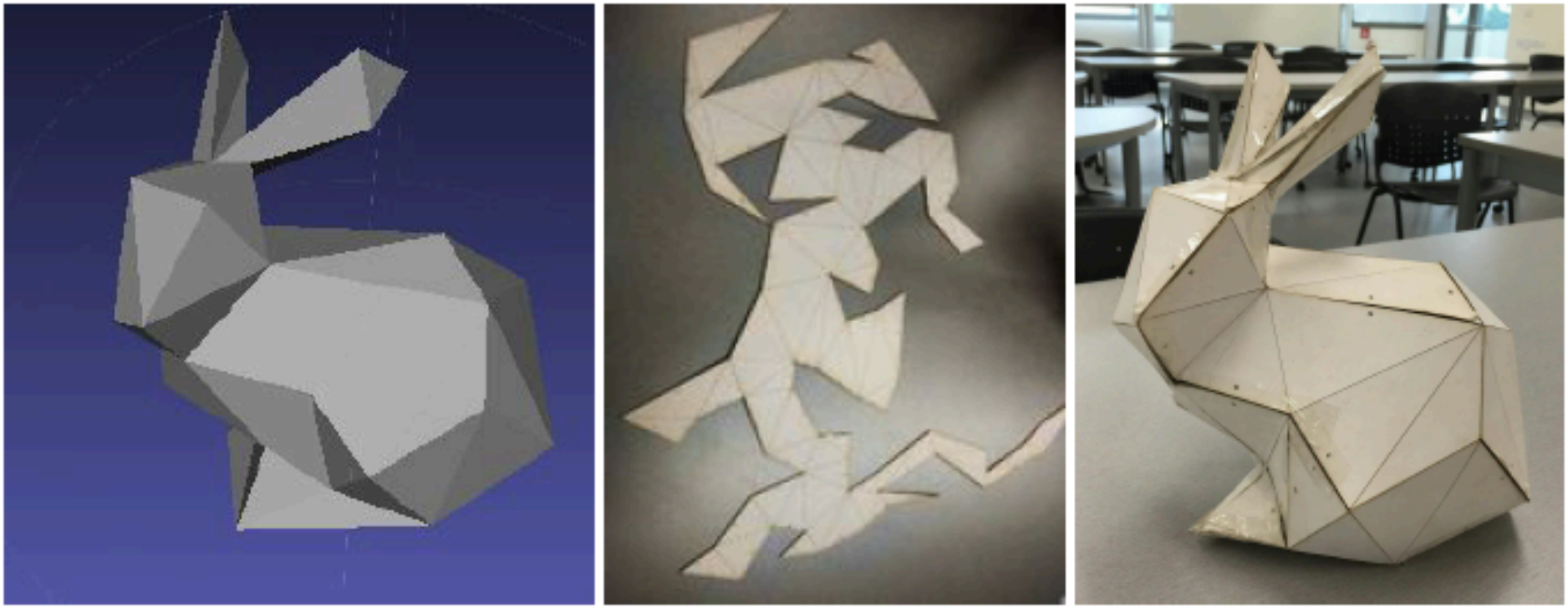
Sample Projects: Strength Optimization of 3D Voronoi Open Cell Structures





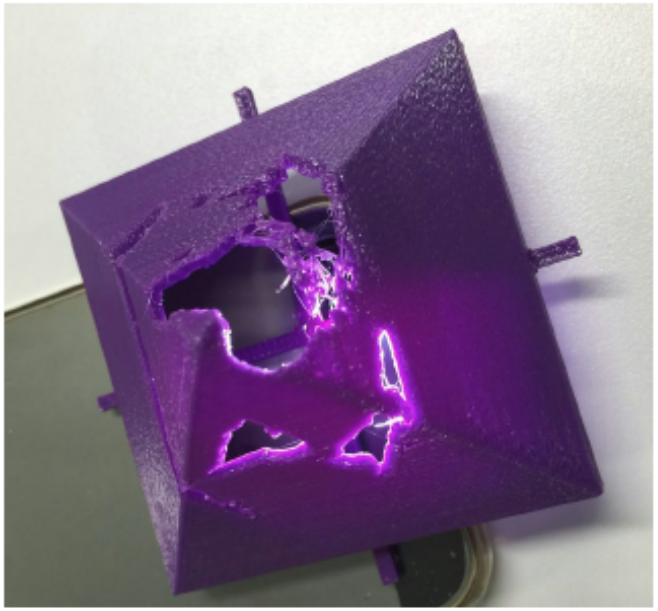


Sample Projects: From mesh to paper



Stanford Bunny. 76 Faces. From left to right: Original Model, Flattened 2D Mesh, reconstructed bunny.

Sample Projects: Lamp shade



Questions?

That’s all for today!