

MICRO-722: 3D PRINTING WITH LIGHT

Professor Christophe Moser, Professor Demetri Psaltis

11 students

Each student presents one paper (Moodle list)

Quizz at end of semester

TOPICS



FOLDER

3D printing of fused silica 



FOLDER

High resolution Optical Components 



FOLDER

Composite materials 



FOLDER

Volumetric Bio Printing 



FOLDER

Advances in layer by layer DLP printing 



FOLDER

Xolography printing 



FOLDER

Graded Index optical components 



FOLDER

2 step photopolymerization 



FOLDER

2 photon printing grayscale and temporal focusing 



FOLDER

Optical Interconnects 



FOLDER

3D printing Metamaterials 

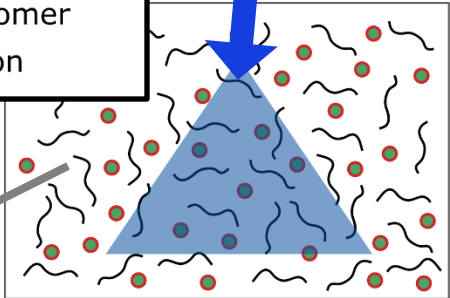
Photopolymerization



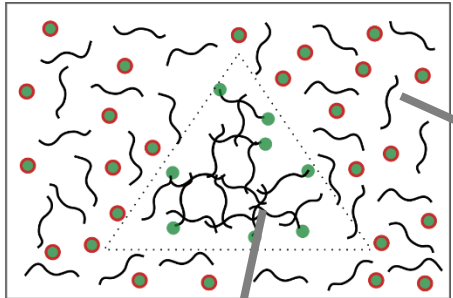
Light Irradiation

- Photoinitiator + Radical
- ~ Monomer/oligomer
- ▲ Light irradiation

Liquid mixture



Liquid part



Solid part

Historical perspective

**New
Scientist**

WEEKLY November 02, 1974

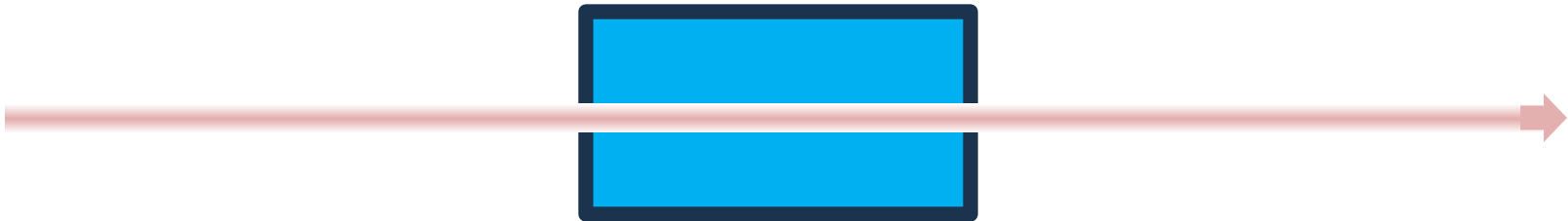
October 3, 1974

David E. H Jones



Jones began with an observation that certain liquid monomers can be polymerized to a solid by light.

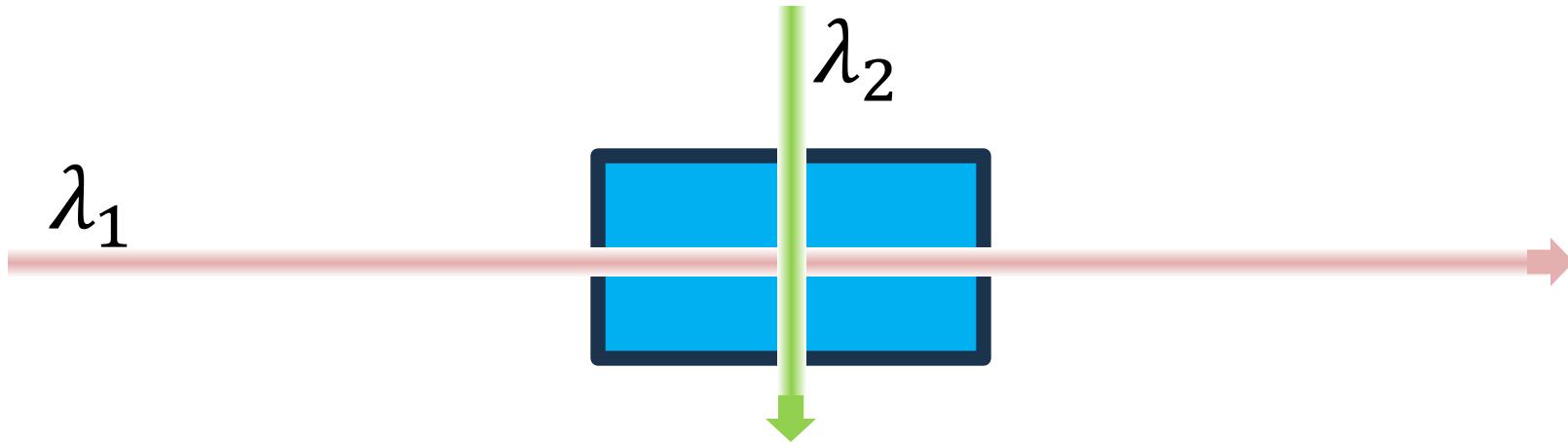
He pointed out that if you were to shine a laser beam of the appropriate frequency through a tank of liquid monomer, you would get a thread.



The question was, how do you get the polymerization to occur at a point rather than along a line?

Historical perspective

But Daedalus, with an eye on profitable production, is devising polymerisation reactions requiring two stages, each catalysed by light of a separate wavelength. Two different laser-beams traversing the tank would then form a solid spot of polymer at their point of intersection.



By scanning this point around, any type of solid object at all could be made up: even complex interlocking and re-entrant shapes quite impossible to mould. This effortless optical sculpture would revolutionise the plastic arts in all senses. Designers would be liberated from heavy, expensive steel moulds, and could try out their fancies at will in the laser-bath. Under programmed numerical control, the beams could reproduce any number of identical objects once the design had been optimized—silent, one-step, infinitely flexible mass production!

Historical perspective August 2, 1981

EPFL

First experimental demonstration of a 3D printing object

Automatic method for fabricating a three-dimensional plastic model with photo-hardening polymer

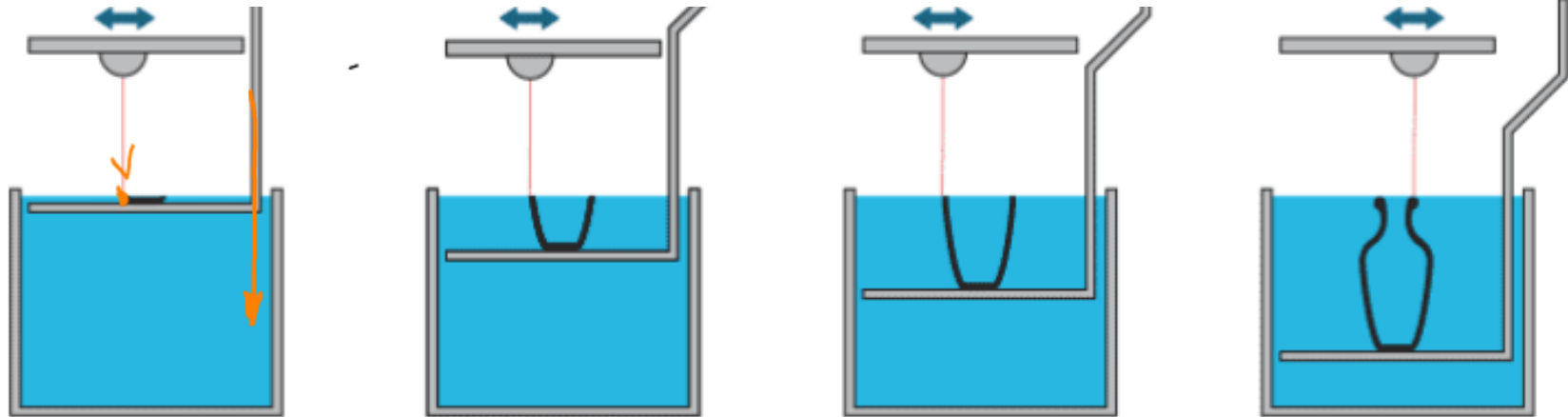
Hideo Kodama

Nagoya Municipal Industrial Research Institute, 3-24 Rokuban-cho Atsuta-ku, Nagoya 456, Japan

(Received 10 February 1981; accepted for publication 2 August 1981)

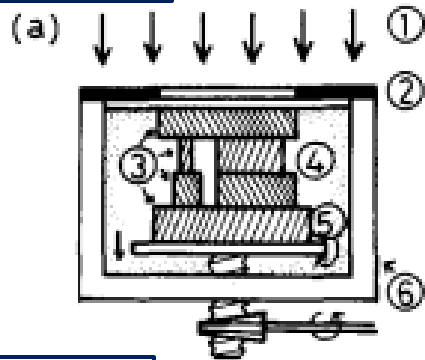


Review of Scientific Instruments,
Vol. 52, Issue 11, Nov. 1981

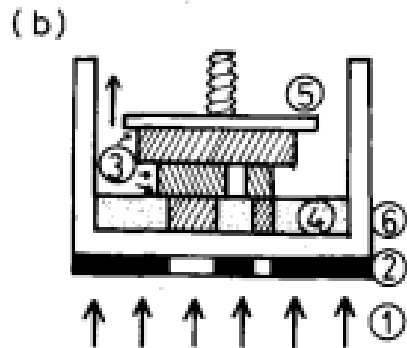


Historical perspective

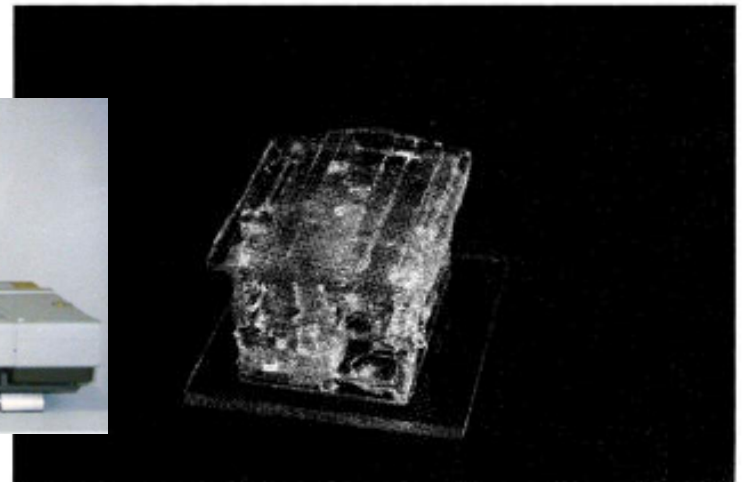
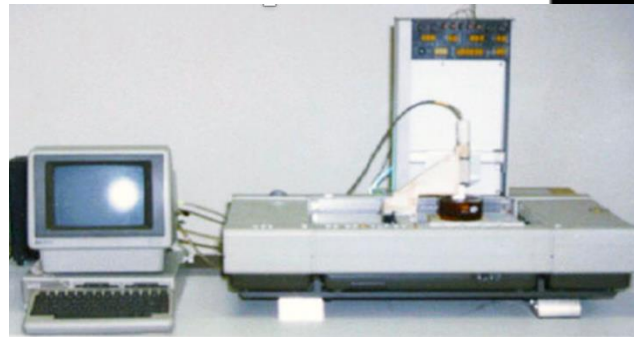
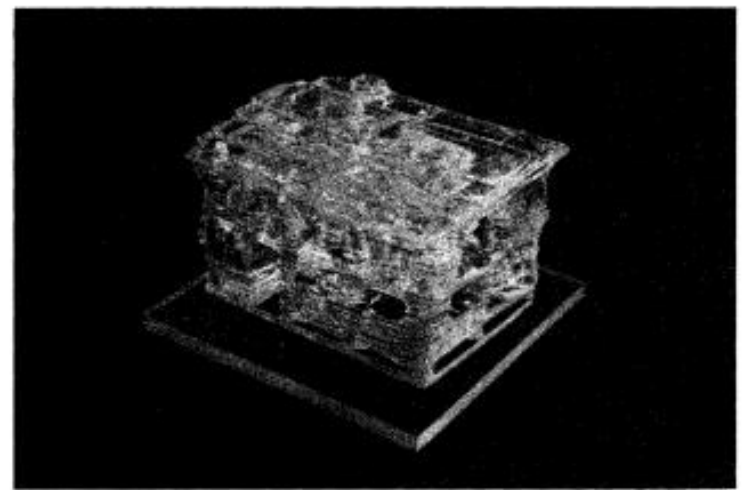
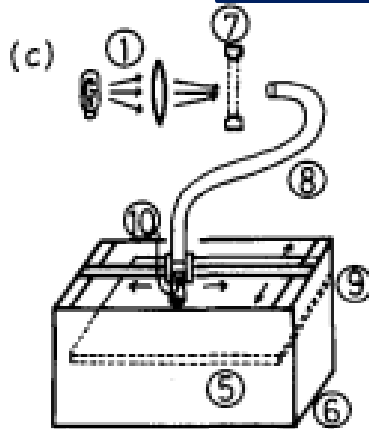
Top-bottom



Bottom-up



Point by Point



MICRO-722

FIG. 7. A house model fabricated by the equipment *a*.

1980: First patent by Japanese Dr. Kodama for Rapid Prototyping : ***“a vat of photopolymer material is exposed to a UV light that hardens the part and builds up the model in layers”***.

Not enough



... the full patent was not filed within the 1-year deadline !

1984: 3 French scientists at CNRS independently discover the same thing, file a patent application on July 16, 1984.

Alcatel – Cilas drop the application **“for lack of business perspective”** !!

1984: In the US, Chuck Hulls independently discovers the same thing, file a patent application on Aug. 8, 1984.

⑫ **DEMANDE DE BREVET D'INVENTION**

A1

②② Date de dépôt: 16 juillet 1984.

③③ Priorité :

④③ Date de la mise à disposition du public de la demande : BOPI « Brevets » n° 3 du 17 janvier 1986.

⑥④ Références à d'autres documents nationaux apparentés :

⑦① Demandeur(s) : *COMPAGNIE INDUSTRIELLE DES LASERS CILAS ALCATEL, société anonyme.* — FR.

⑤④ Dispositif pour réaliser un modèle de pièce industrielle.

⑦② Inventeur(s) : Jean-Claude André, Alain Le Mehauté et Olivier De Witte.

⑦③ Titulaire(s) :

United States Patent [19]
Hull

[11] **Patent Number:** **4,575,330**

[45] **Date of Patent:** **Mar. 11, 1986**

[54] **APPARATUS FOR PRODUCTION OF THREE-DIMENSIONAL OBJECTS BY STEREO LITHOGRAPHY**

[75] **Inventor:** Charles W. Hull, Arcadia, Calif.

[73] **Assignee:** UVP, Inc., San Gabriel, Calif.

[21] **Appl. No.:** 638,905

[22] **Filed:** **Aug. 8, 1984**

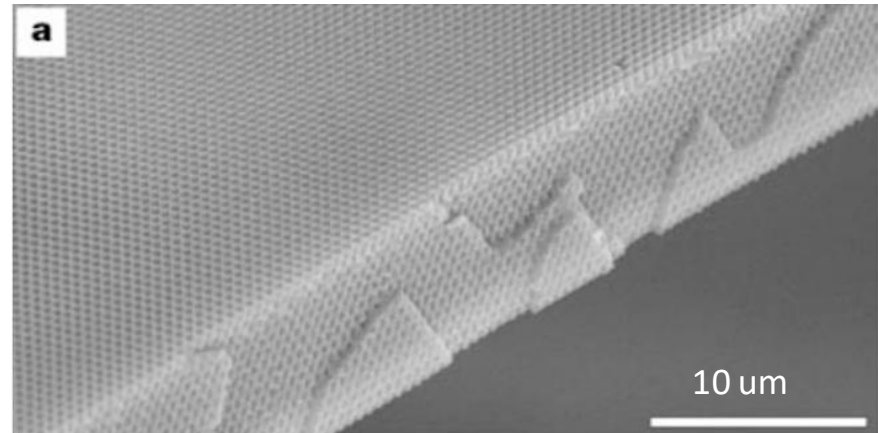
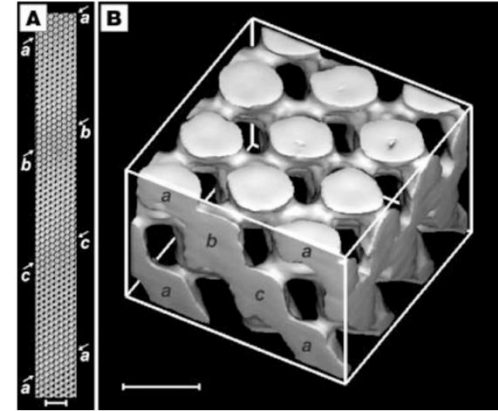
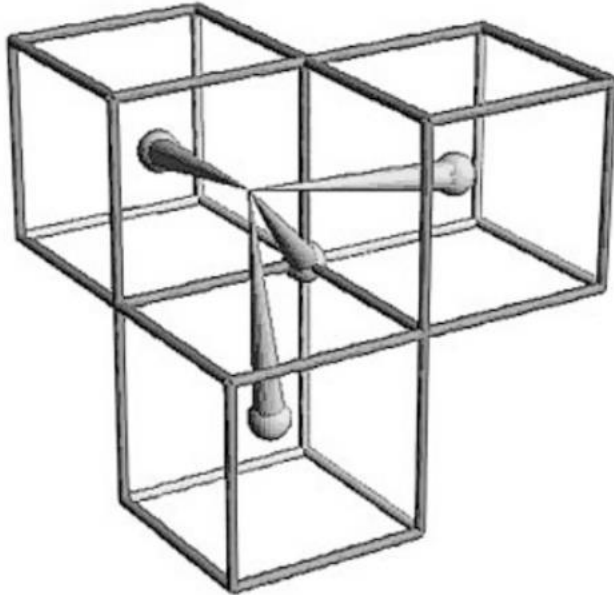
4,252,514	2/1981	Gates	425/162
4,288,861	9/1981	Swainson et al.	365/127
4,292,015	9/1981	Hritz	425/162 X
4,329,135	5/1982	Beck	425/174
4,333,165	6/1982	Swainson et al.	365/127 X
4,374,077	2/1983	Kerfeld	264/22
4,466,080	8/1984	Swainson et al.	365/127 X
4,471,470	9/1984	Swainson et al.	365/127

Primary Examiner—J. Howard Flint, Jr.

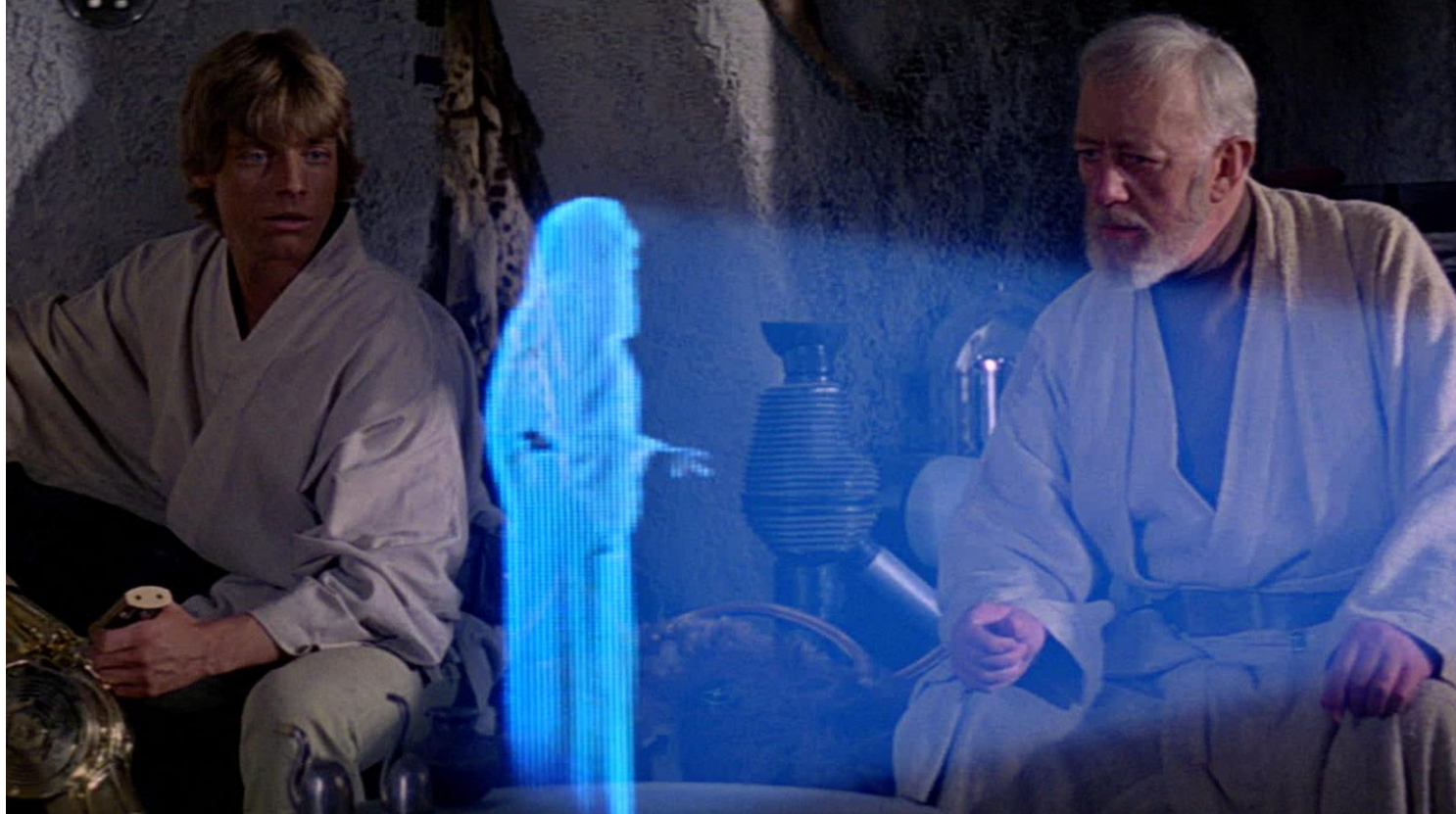


Fabrication of photonic crystals for the visible spectrum by holographic lithography

M. Campbell*, D. N. Sh
& A. J. Turberfield* NATURE | VOL 404 | 2 MARCH 2000 |

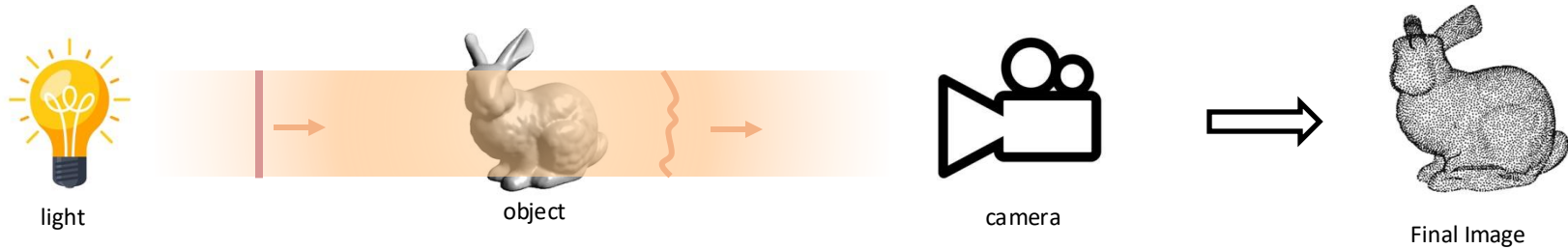


Holography?



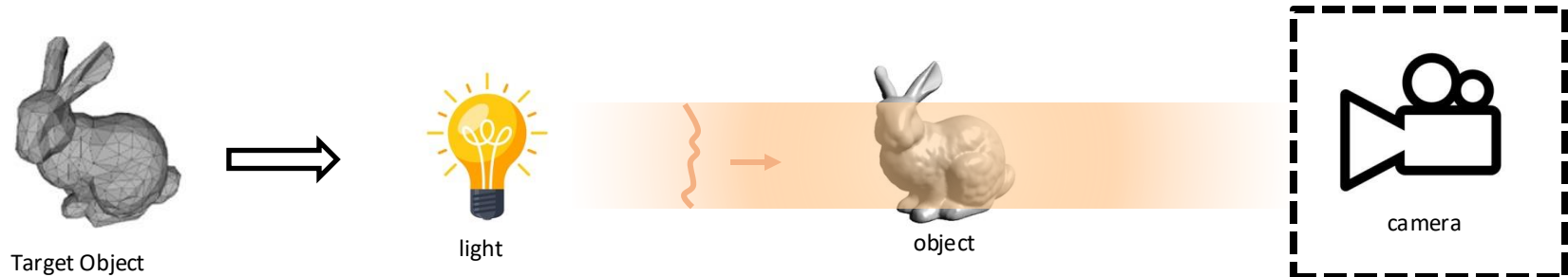
From imaging to printing objects

- Optical Imaging



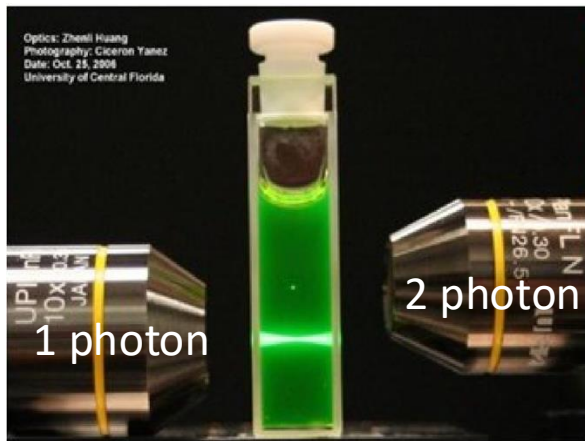
The goal is different, the problem is reversed, physics is the same

- Printing with light



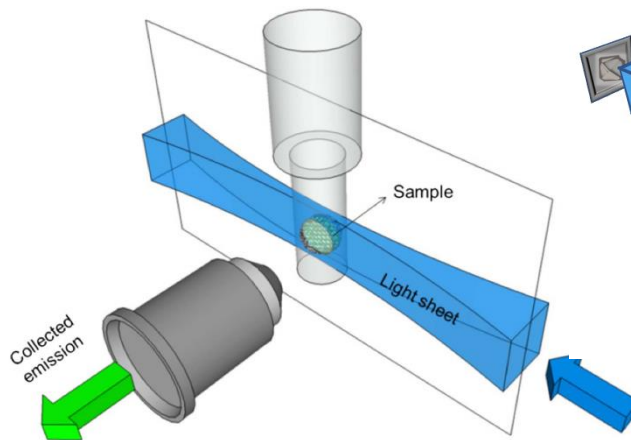
A detour to 3D imaging

2 Photon imaging



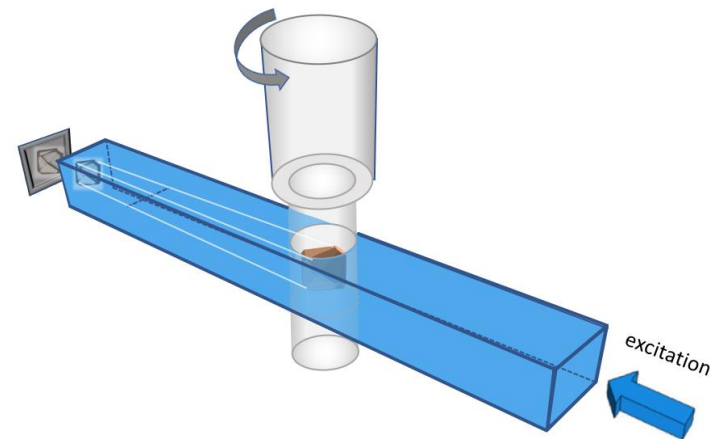
Denk W., Strickler J., Webb W.
Two-Photon Laser Scanning Fluorescence Microscopy
 Science, 248, 4951, 1990

Light Sheet



Voie A.H, Burns D.H, Spelman F.A
**Orthogonal-plane fluorescence optical sectioning
 Three-dimensional imaging of macroscopic
 biological specimens, Journal of Microscopy, 1991**

Tomography



- [54] **METHOD AND APPARATUS FOR MEASURING X- OR γ -RADIATION ABSORPTION OR TRANSMISSION AT PLURAL ANGLES AND ANALYZING THE DATA**
- [75] Inventor: **Godfrey Newbold Hounsfield, Winthorpe Aerodrome Farm, near Newark, England**
- [73] Assignee: **EMI Limited, Hayes, Middlesex, England**
- [22] Filed: **Dec. 27, 1971**

Volumetric true 3D printing

2 Photon printing



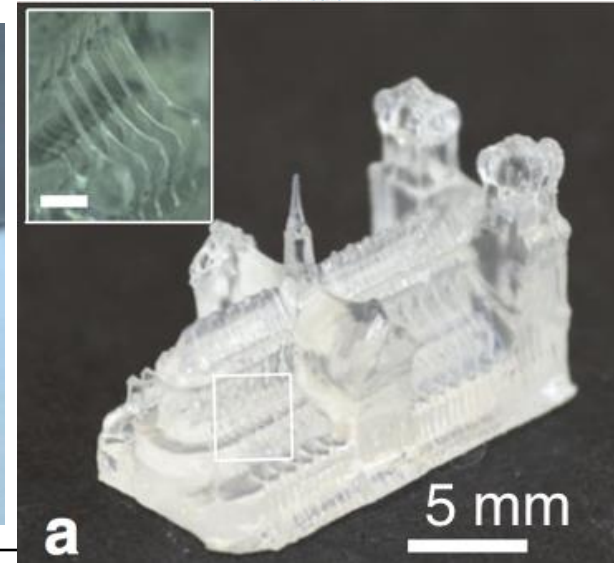
Maruo S., O. Nakamura, Kawata S., "Three-dimensional microfabrication with two-photon-absorbed photopolymerization," *Opt. Lett.* 22, 132-134 (1997)

Xolography



Regehly *et al.* 2020. Xolography for linear volumetric 3D printing. *Nature*, 88, 620–624 (2020)

Tomographic Printing



Bernal, *et al.*, Volumetric bioprinting of complex living-tissue constructs within seconds. *Adv. Mat.* (2019)

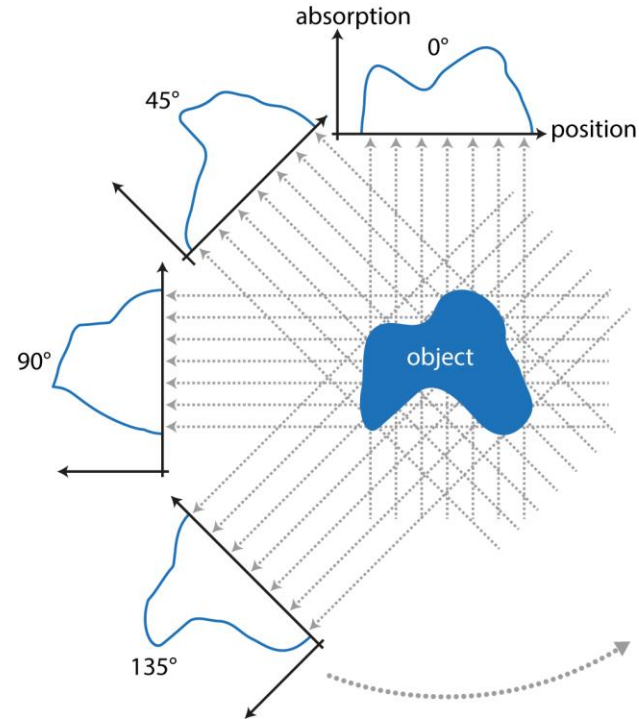
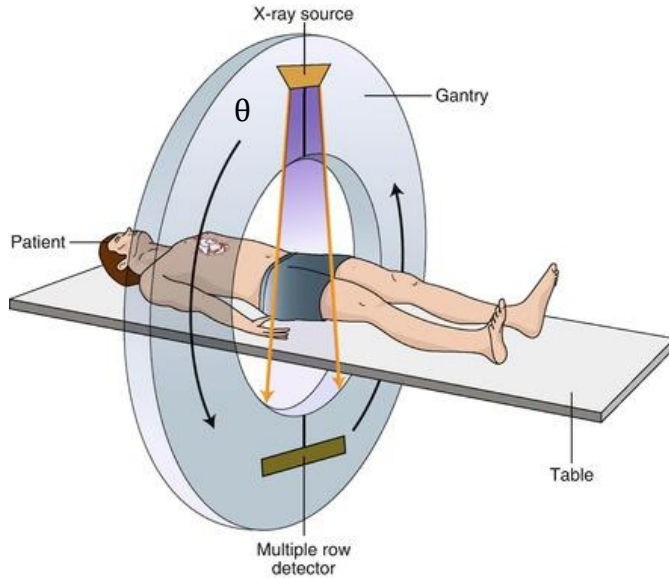
Loterie, *et al.*. High-resolution tomographic volumetric additive manufacturing. *Nat Com.* (2020)

Kelly, *et al.*. Volumetric additive manufacturing via tomographic reconstruction. *Science* (2019)

Principle of Tomographic printing

Computed Tomography imaging

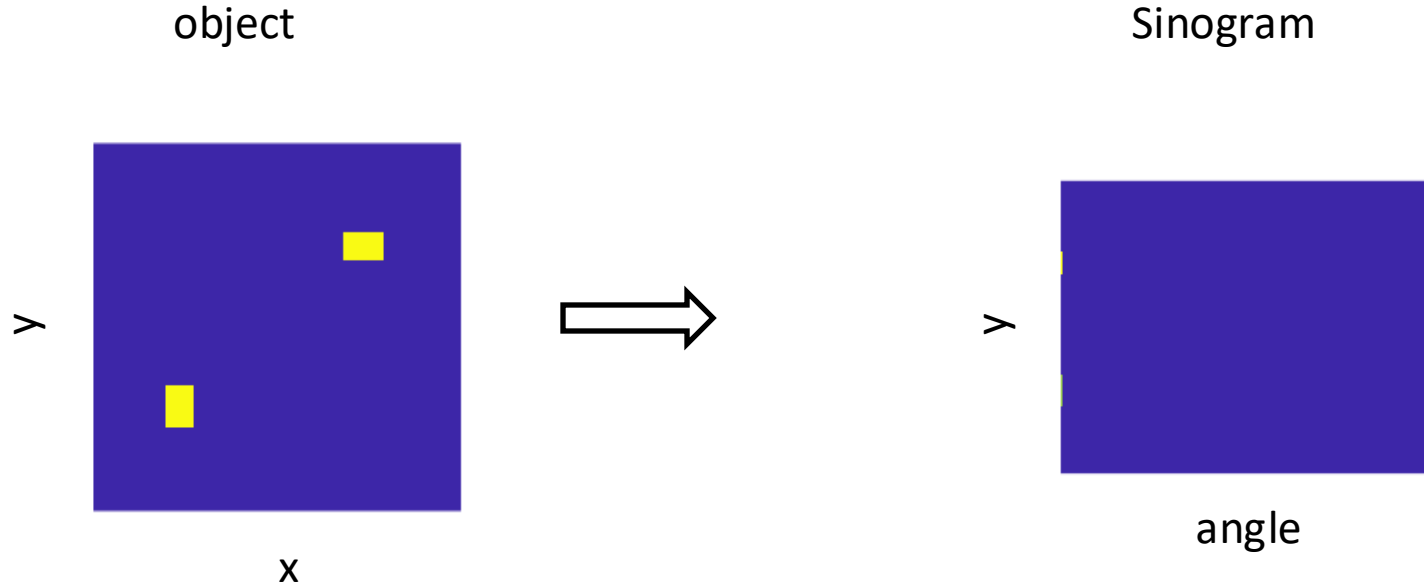
2D + θ
measurements



3D reconstruction



Tomography: principle



Tomography: reconstruction principle

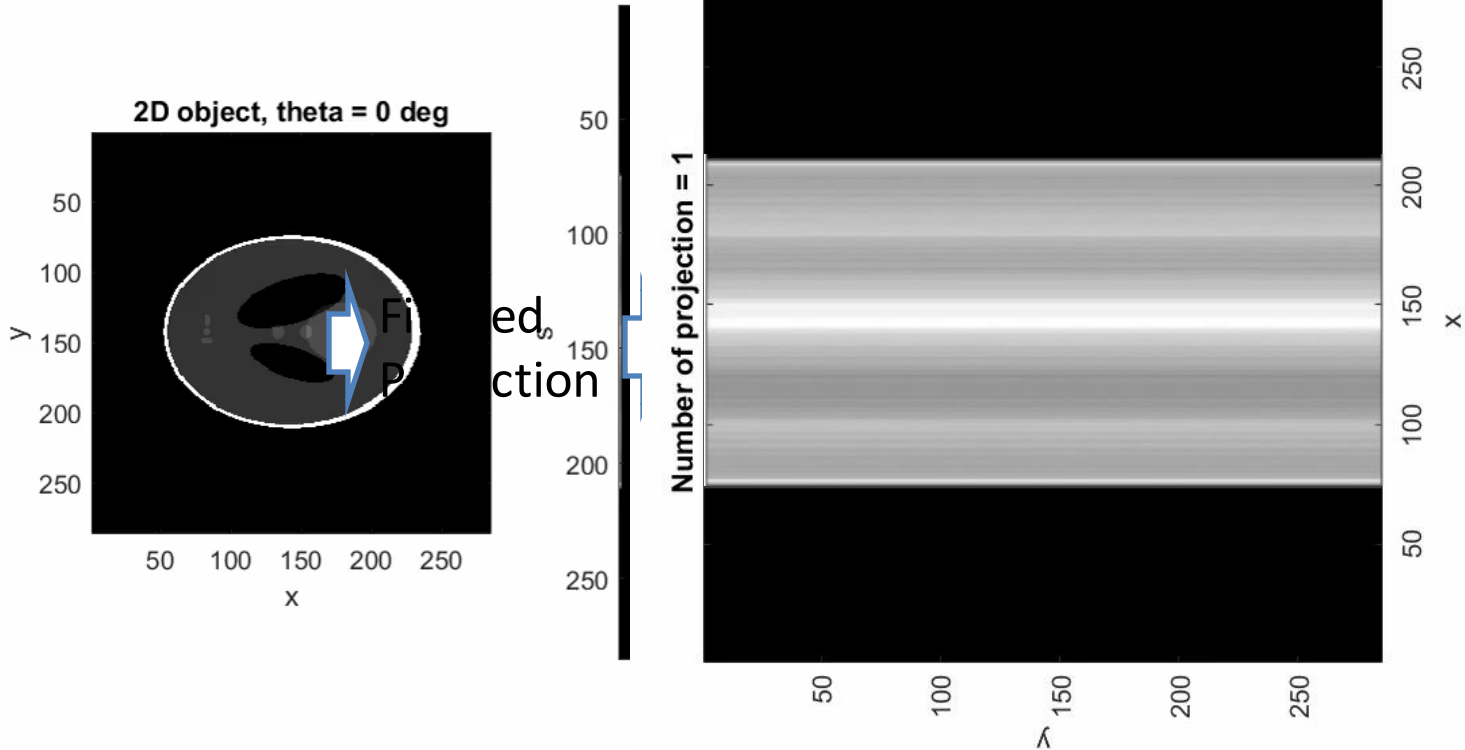
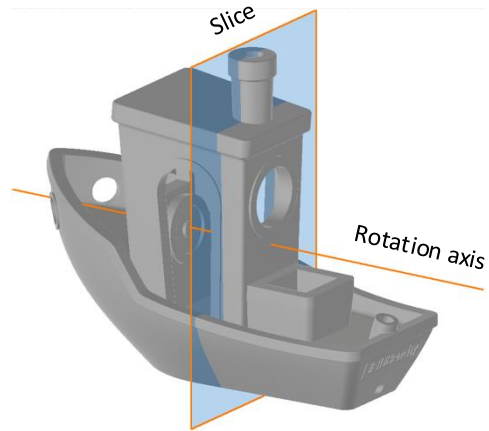
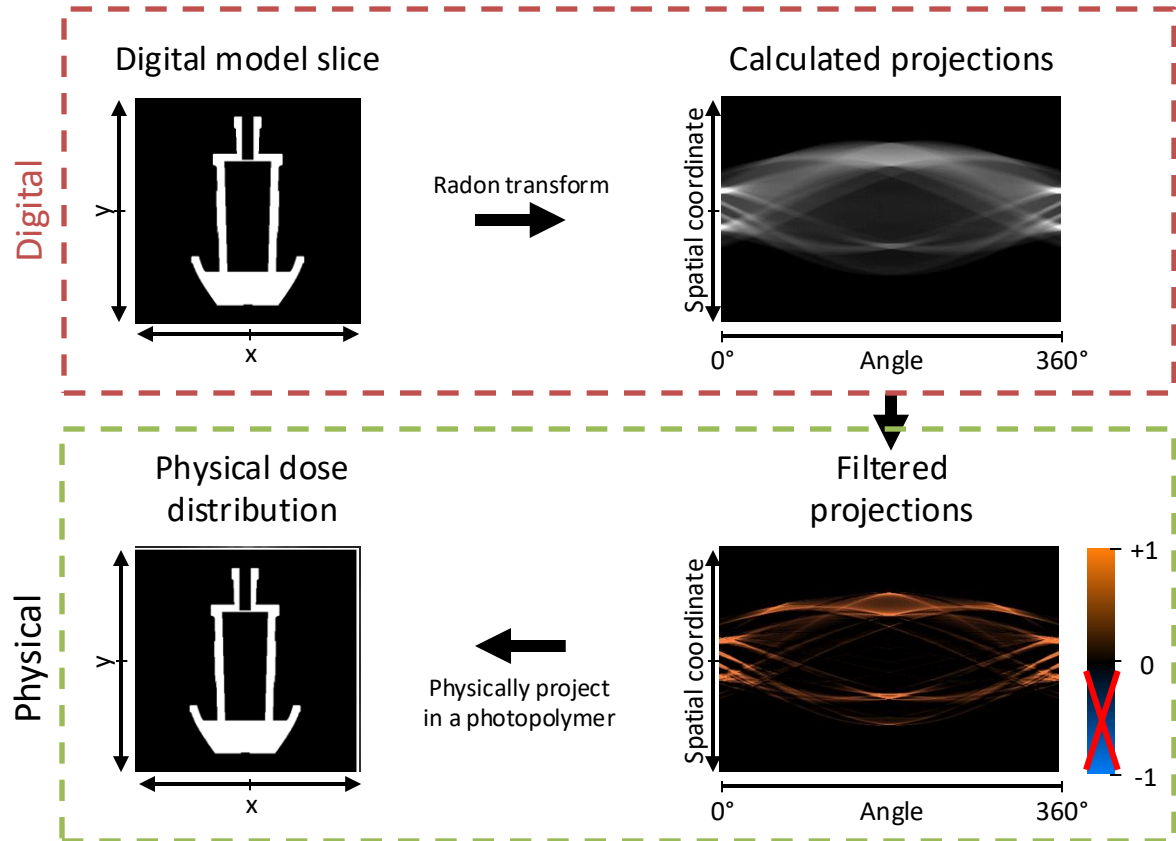


Illustration of the Radon transform in 3D printing **EPFL**

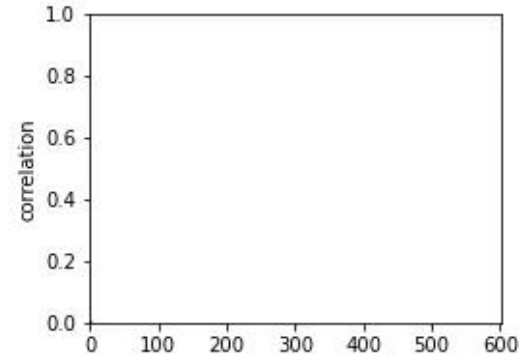
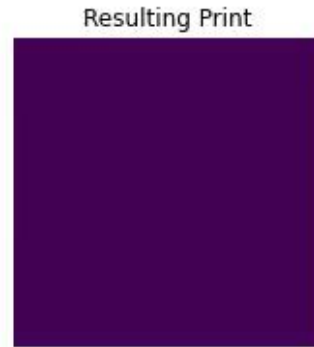
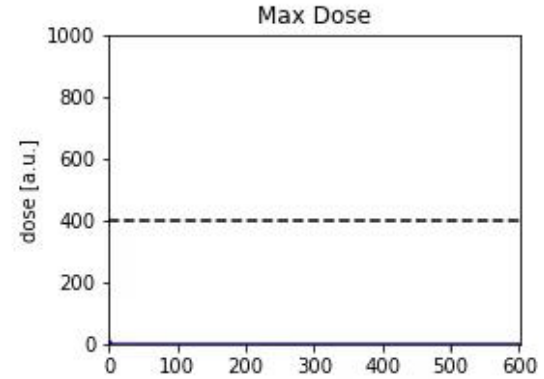
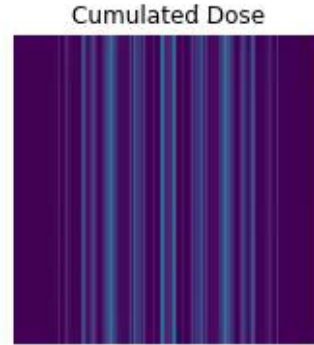
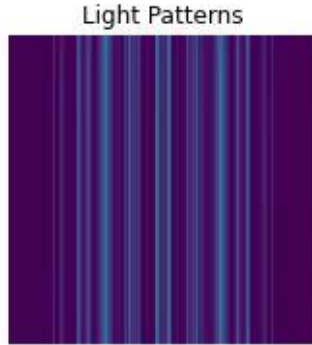


3D object

(3DBenchy by Creative Tools, license CC BY ND 4.0)



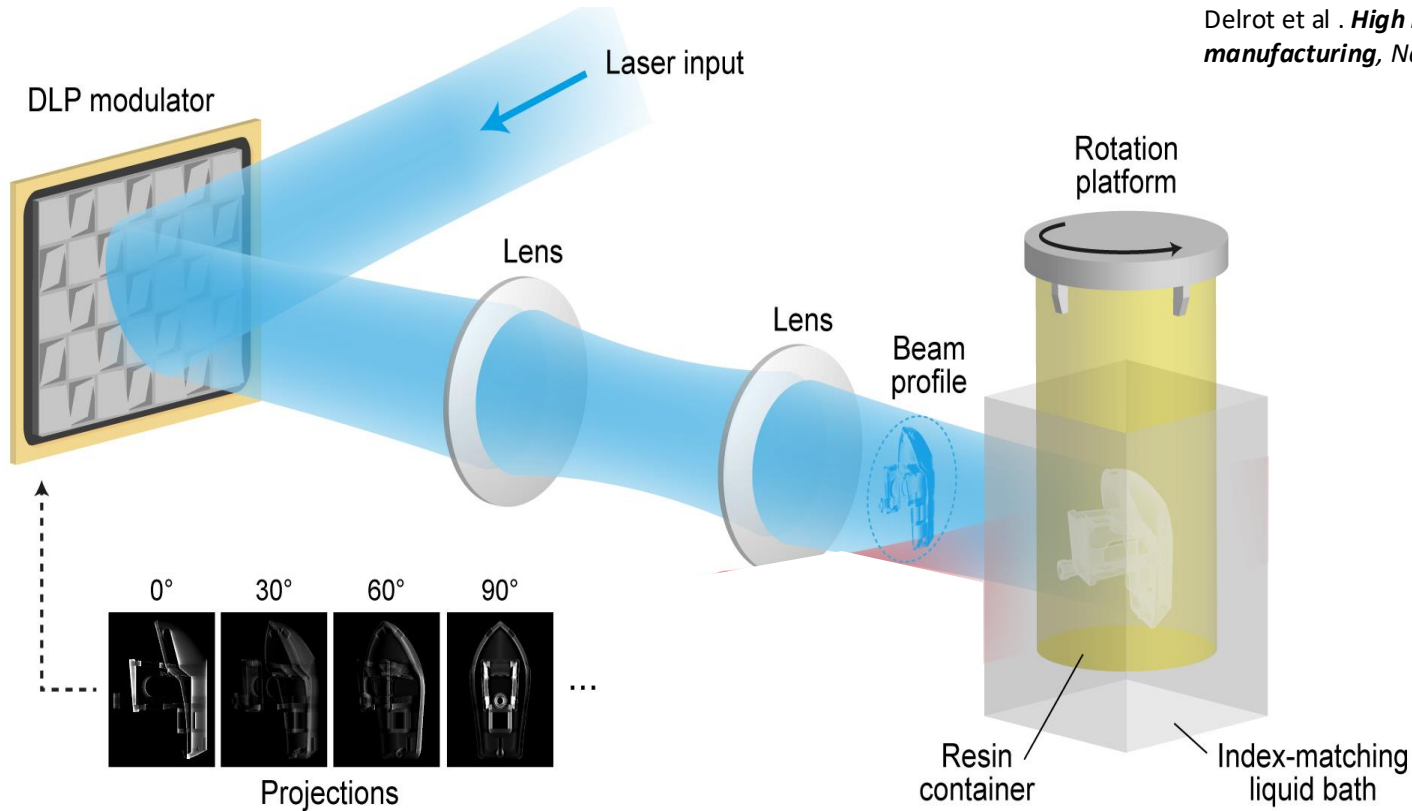
Reverse tomography for 3D printing



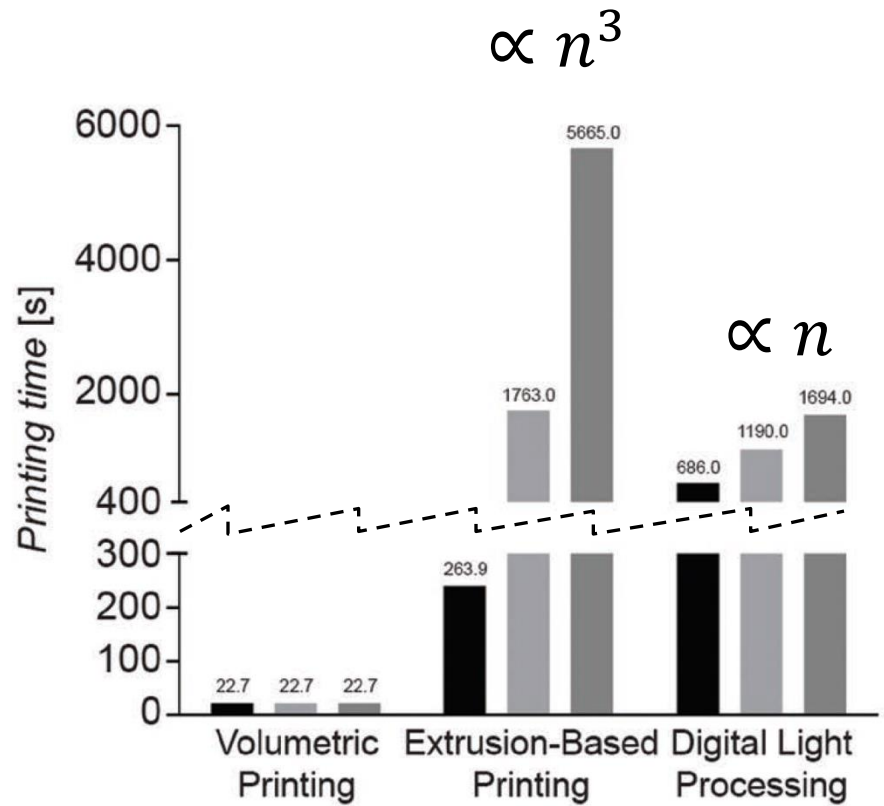


Feedback assisted volumetric printing

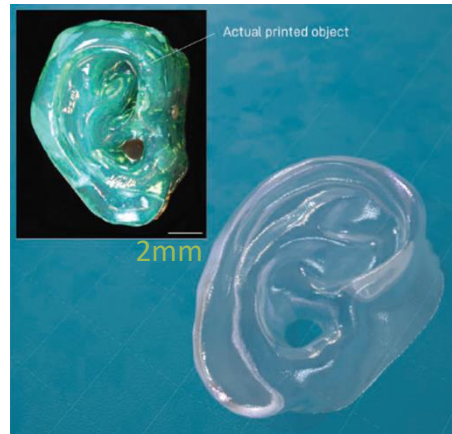
Delrot et al . *High resolution volumetric additive manufacturing*, *Nat. Comm.*,11,852 , 2020



PRINTING SPEED



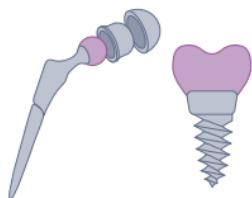
- Scaled 1x
- Scaled 2x
- Scaled 3x (4 cm³)



The road ahead in materials and technologies for volumetric 3D printing

Paulina Nunez Bernal¹, Sammy Florczak^{1,2}, Sebastian Inacker³, Xiao Kuang^{4,5}, Jorge Madrid-Wolff⁶, Martin Regehly⁷, Stefan Hecht³, Yu Shrike Zhang^{4,8,9}, Christophe Moser⁶ & Riccardo Levato^{1,2}✉

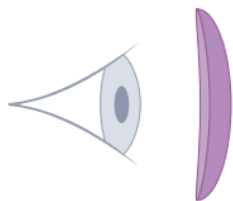
a Ceramics, glass and polymers



Ceramic implants



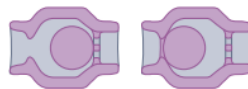
Polymeric parts



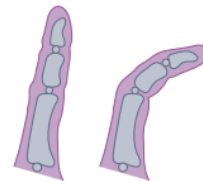
Lenses and optical elements



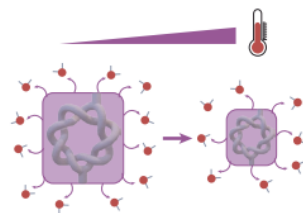
b Soft robots and free-moving parts



Actuated fluidic devices



Jointed parts and soft grippers



4D printing

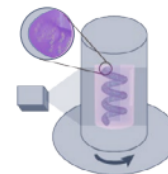


Metamaterial design

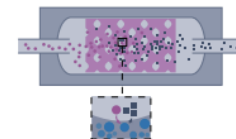
c Living materials



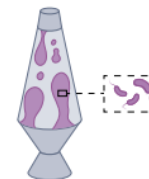
Biological implants



Biomolecule patterning



Drug testing and disease modelling platforms



Engineered living materials

Silicone

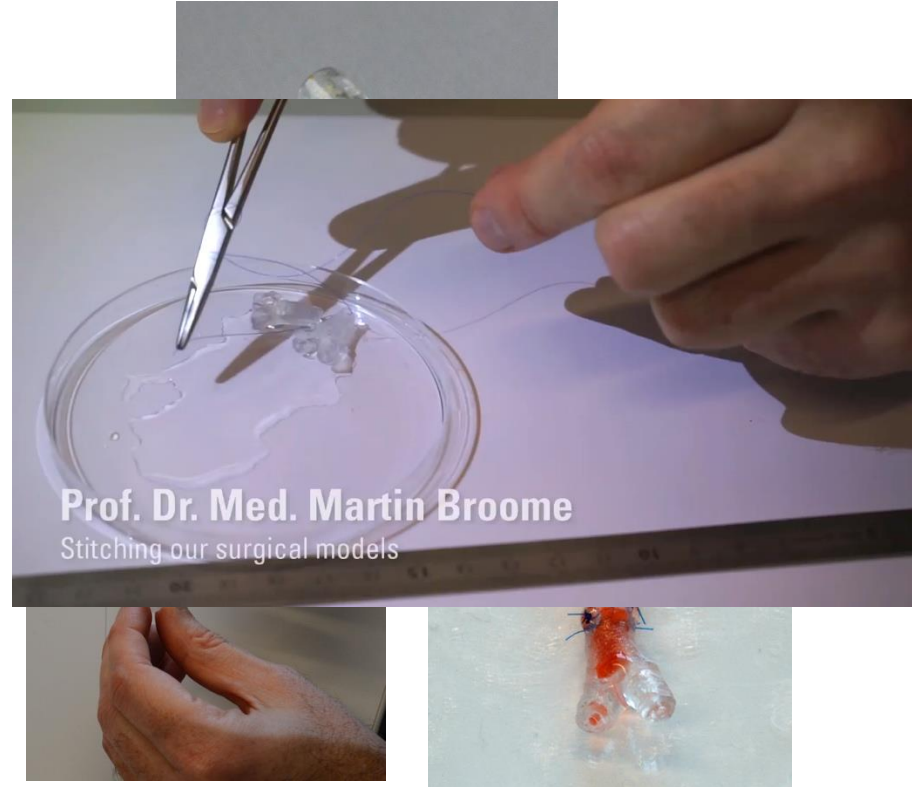
Soft hearing aid shell



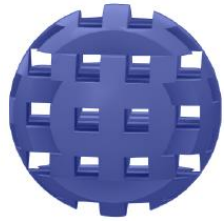
Main cavity

Side vent

Arterial junction model

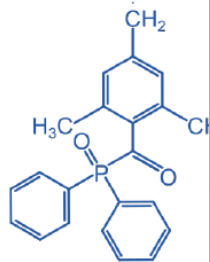
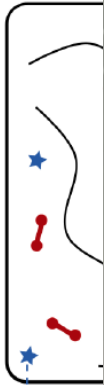


Prof. Dr. Med. Martin Broome
Stitching our surgical models



3D model

Liquid



Photoinitiator



Crosslinker



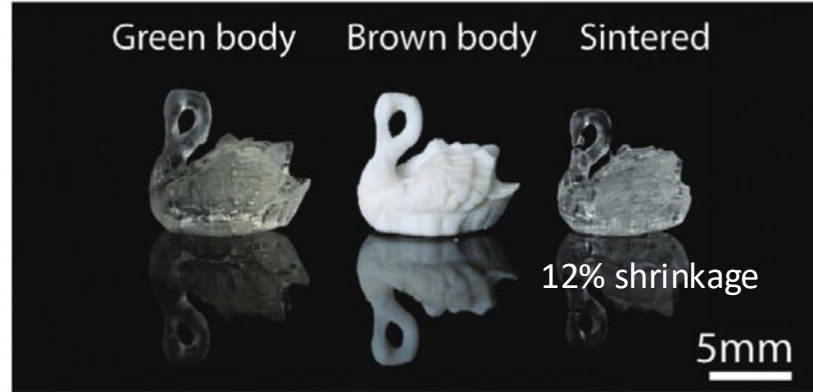
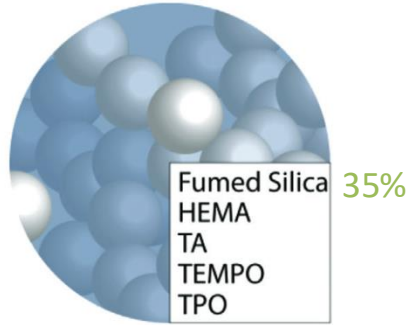
Ceramic



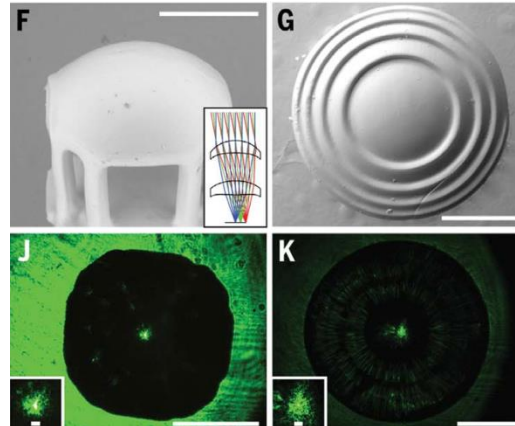
Silicon Dioxide

1mm

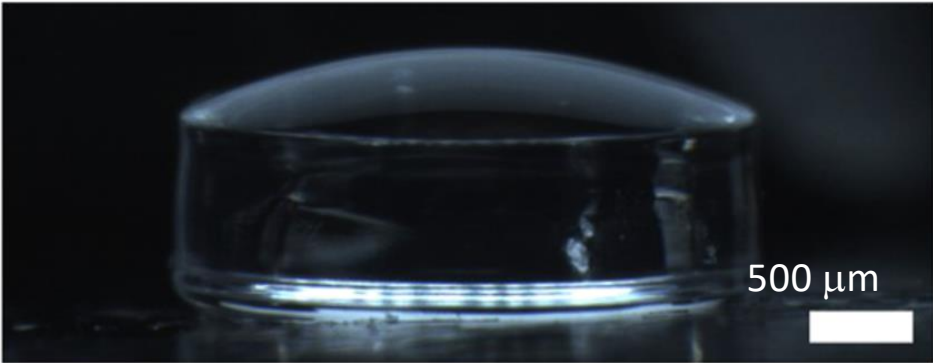
<https://arxiv.org/abs/2109.12680>



Barbera et al *Multimaterial Volumetric Printing of Silica-Based Glasses*, *Adv Material Technol.* 2024

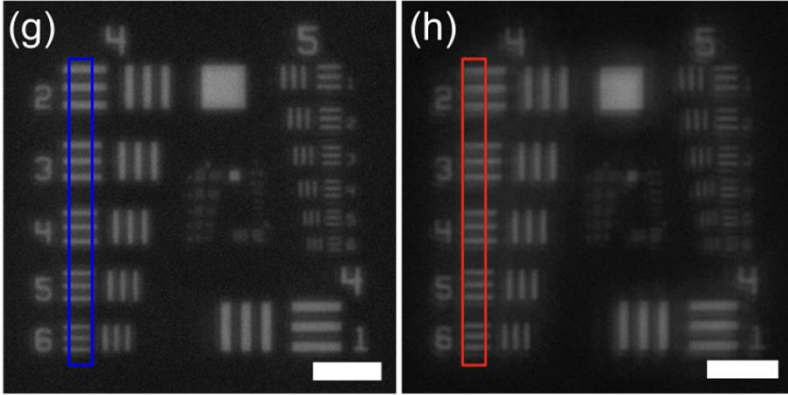
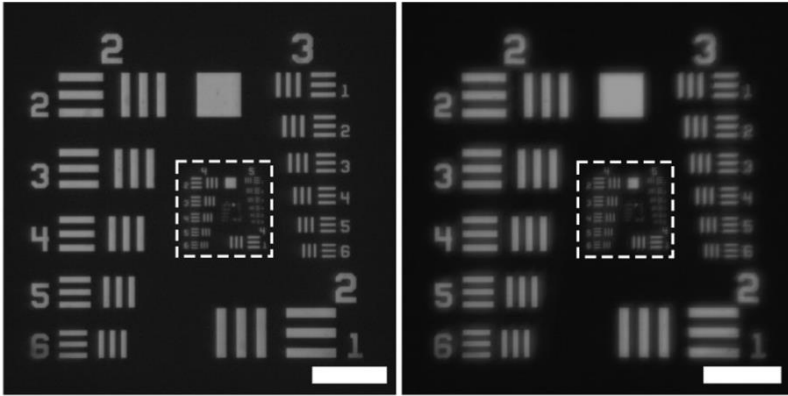


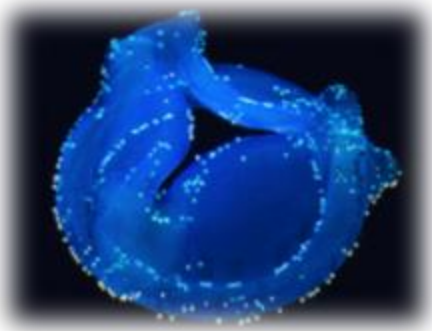
Toombs et al , *Volumetric additive manufacturing of silica glass with microscale computed axial lithography*, *Science*, 376, 2022



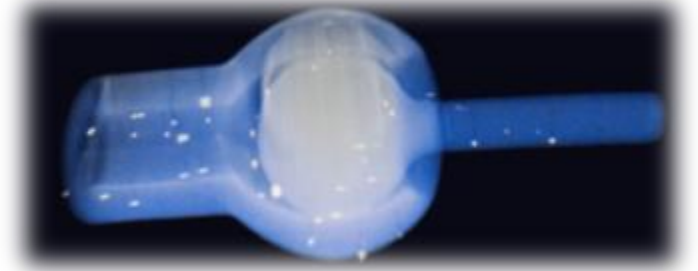
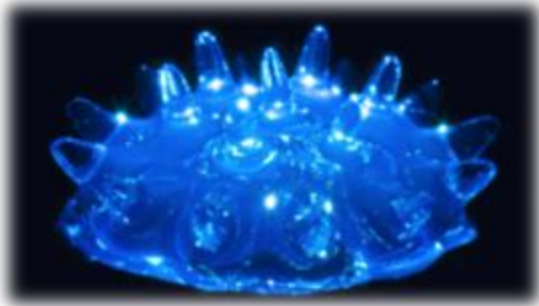
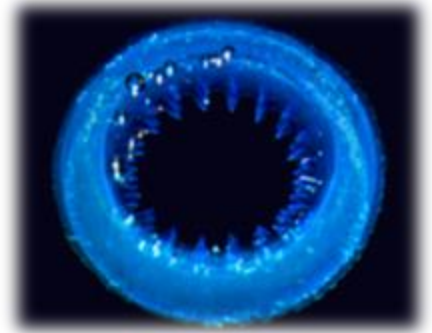
Webber et al, *Micro-optics fabrication using blurred tomography*, *Optica*,11,5 2024

(c) Glass Lens (d) VAM Printed Lens





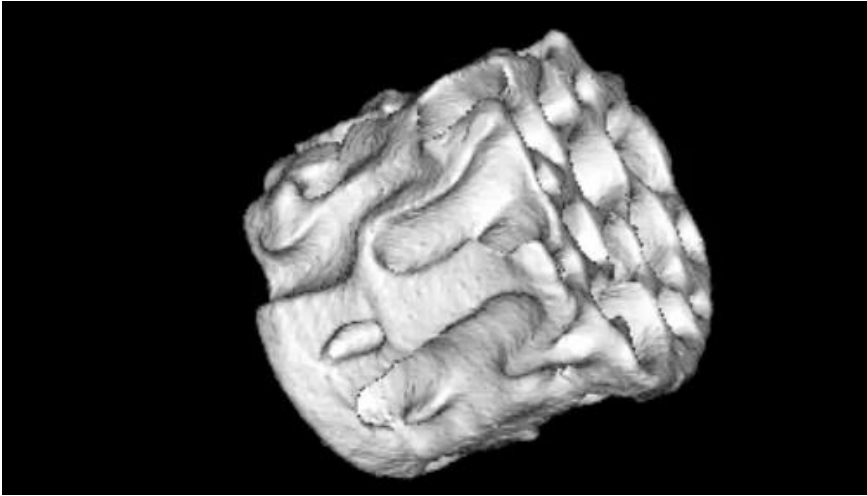
Volumetric Bioprinting with soft hydrogels Synthetic Biology



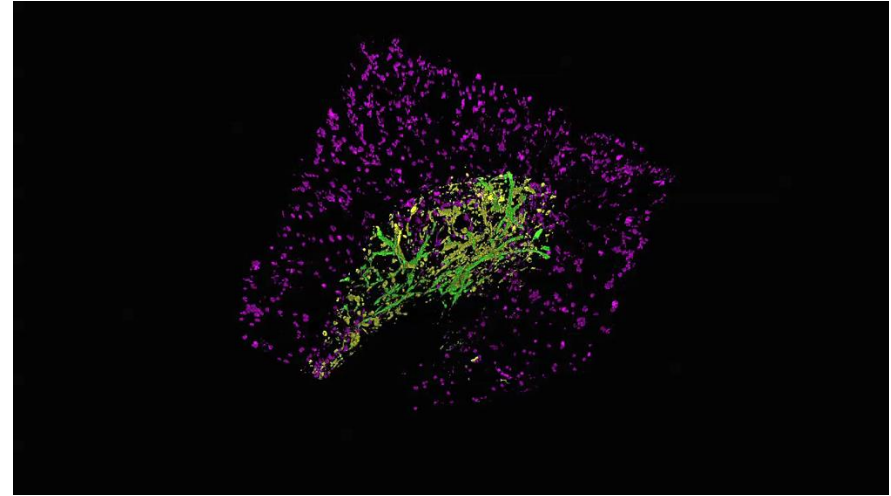


Pour the cell-seeded ink into a sterile vial

Trabecular Bone construct



MSC cells in GelMA



Bernal P.N,et al. "Volumetric Bioprinting of Complex Living-Tissue Constructs within Seconds", Adv. Materials, 2019