Digital Fabrication Technologies

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Vince Cahill & Patrice Giraud, VCE Solutions

VCE Solutions

Vince Cahill

- Printer for over 20 years
- Consultant and journalist for over 17 years
- Former CEO of Datametrics, owner of the Colorworks, Industrial Printing Solutions, Specialty Materials, Newhill Technologies
- President of VCE Solutions, Digital Print & Fabrication Technology and Market Consultancy 717-762-9520
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Patrice Giraud

- One of five founders of IMAJE: engineered continuous inkjet systems from 1982 to 1993
- Founder of EMBLEME: developed the first inkjet garment printing system 1993-1997
- Founder of ARDEJE, developer of inkjet printing systems 1997-2000
- Associate Professor at ESISAR school of INPG 1996-2008
- Director of the Pôle Impression Numérique 2003-2008
- Contributing Member VCE Solutions Group 2008-present
- patrice@vcesolutions.com

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- Analog & digital print & digital fabrication technology & market investigation, facilitation, development & training
- Application development. Applications give technology relevance
- Discerning market & technology patterns
- Discovering process and market failure modes

Program: A Catalog in Context

- History, science, technology and society
- Origins of subtractive & additive digital fabrication
- Broad overview of digital additive & additive-subtractive fabrication technologies: processes, providers, applications & limitations – a catalog
- In the beginning, meaning & robotic technologies, the probable & the possible

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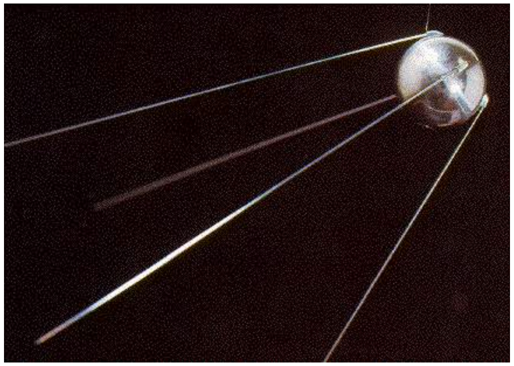
Notable Historic Markers

- 54 years ago today, Sputnik became the first man-made object to orbit Planet Earth
- Less than 12 years later, humans walked on Earth's moon
- About 35,000 years before …



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Lascaux, France: Aurochs, ancestors of the modern cow

Lascaux Two, is a copy of two of the cave halls

Chauvet, Lions hunting bison

Science, Technology & Society

- Scientific process & mentoring
- Hunter-gatherers to 7 (8, 9) billion humans
- Human history from cave paintings to robotics
- Capitalism, sustainability, the redefinition of growth, technology & the warming planet
- Digital fabrication- "The next big thing": tool or chain? For good or ill?

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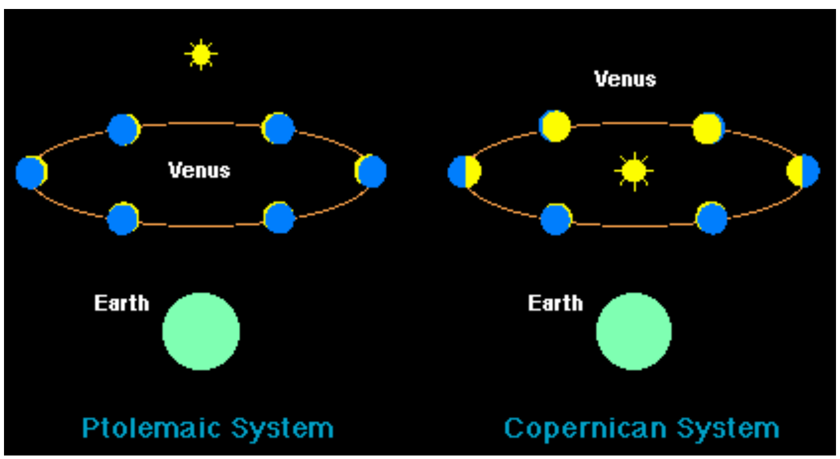
The Chain of Humanity



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Necessary Ingredients for the Success of Technology Development

- History & knowledge-based company culture
- Method, training & skills
- Challenge, desire & vision ➡ joie de vivre
- Applications that satisfy market demands
- Resources, conditions, business model, time, money, investment, marketing & sales
- Consumers with expendable income; who has money?

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Digital Subtractive Fabrication Origins

- Beginning in 1946, John T. Parsons and Frank L. Stulen developed the first numerical controlled (NC) machining system for the precision manufacture of helicopter rotor blades
- Developed CNC with MIT and IBM
- On May 5, 1952, Parson filed for a patent, *Motor Controlled Apparatus for Positioning Machine Tool*. Awarded US Patent 2,820,187 (Jan 1958)
- CAD➔Interface➔CNC
- Input➔Process➔Output
- Lathe-turning, drilling, honing, milling (routing, surface finishing-sink & slot), grinding, cutting

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Digital Additive Fabrication Origins

- Stereolithography (SLA): Chuck Hull, 1986 - 3D Systems, US Patent 4,575,330
- First rapid prototyping system: SLA 1

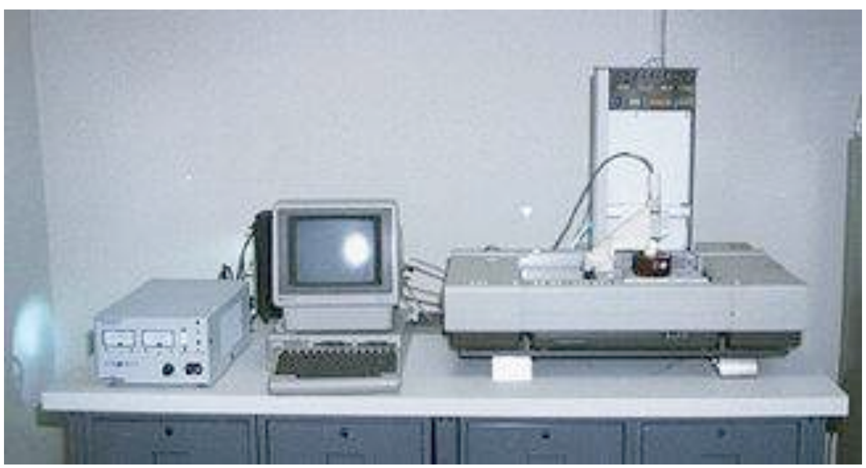

Photo source: 3D Systems

- Selective Laser Sintering (SLS): Dr. Carl Deckard, of the Univ. of Texas at Austin, US Patent 4,863,538 filed Oct. 17, 1986, published Sept. 5, 1989.
- R. F. Housholder patented a "Molding Process" similar to SLS, US Patent 4,247,508, filed Dec. 3, 1979, published Jan. 27, 1981

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System Performance Criteria

- Production speed (finished product cm^2/hr.) and production scale
- Build volume
- Precision & reproduction resolution
  - Process artifact visible with layers >30µm
- Fabrication materials
- Application capabilities
- Cost effectiveness:
  - Capital expense
  - Operational expense
- Sustainability (amount of waste & hazard)

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Production Scale

1. Prototype model
2. Functional model
3. Custom production
4. Short run production
5. Mass production

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Digital Fabrication Technologies

- Stereolithography (SLA) + (MSL), (FMSL) & (MLS)
- Film Transfer Imaging (FTI)
- Selective Laser Sintering (SLS)
- Selective Laser Melting (SLM)/ Laser cladding (LC)
- Laser Engineered Net Shaping (LENS)
- Selective Area Laser Deposition (SALD)
- 3D Inkjet (3DIJ), Polyjet Modeling (PJM) & Multijet Modeling (MJM)
- Inkjet Liquid Binding Powder (IJLBP)
- Robo-casting (RC)
- Electron Beam Melting (EBM)
- Electron Beam Freeform Fabrication (EBF^3)
- Fused Deposition Modeling (FDM)
- Cold Metal Transfer (CMT)
- Shaped Deposition Manufacturing (SDM)
- Laminated Object Manufacturing (LOM)
- Solid Ground Curing (SGC)
- Ultrasonic Consolidation (UC) (UAM)
- Very High Power Ultrasonic Additive Manufacturing (VHP UAM)
- Integrated extrusion deposition (IED/PED)
- Near field electro-spinning (NFES)
- Bio-fabrication (BIO)

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Digital Fabrication Categories

- SLA-type laser UV cure of polymers:
  - SLA, MSL, FMSL, MLS, FTI
- Laser sintering and melting:
  - SLS, SLM, LC, LENS, SALD
- E-beam melting:
  - EBM, EBF3
- Ultrasonic welding:
  - UC/UAM, VHFUAM
- 3D inkjet and fluid deposition:
  - 3DIJ, PJM, MJM, IJLBP, RC, (BIO)
- Wire & extruded welding:
  - FDM, CMT, IED/PED
- Hybrid additive & subtractive:
  - SDM, LOM, SGC

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Materials

- Photopolymers
- Polymer + tricalcium phosphate
- Polymers: Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polypropylene (PP), High-density Polyethylene (HDPE), Low-density Polyethylene (LDPE), Un-plasticized Polyvinyl Chloride (uPVC), Polyimide (PI), Polycarbonate (PC), Polyphenylsulfone (PPSF/PPSU)
- Low temperature wax-like polymers
- Optical fiber
- Metals: aluminum, titanium, nickel, cobalt, chrome, stainless, tool steel, steel alloys, silver, gold, copper, zirconium, niobium, lead zirconate titanate, tantalum, alumina, hydroxyapatite colloidal particles
- Ceramics, silicon carbide, silica
- Glass beads, carbon fibers
- Paper + adhesive
- Bio-polymers
- Plant & animal cells

Industries Using Digital Fabrication

1. Advertising
2. Aerospace
3. Animation
4. Architecture
5. Art
6. Automotive
7. Building Construction
8. Consumer Goods
9. Defense
10. Dental

A. Electronics & Photovoltaics
B. Entertainment
C. Hearing Aids
D. Jewelry
E. Medicine
F. Medical Equipment
G. Industrial Machinery
H. Service Bureau
I. Sporting Goods
J. Toy

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	2009-2012	2012-2017	2018+
Organic Photovoltaic	Consumer electronics & first off-grid app	Off-grid power & building integration	Grid connected power generation
Flexible Display	Price labels, e-readers	High resolution color e-readers, e-posters	Electronic wallpaper, roll-able OLED TVs
OLDE/EL Lighting	Small lamps, design and decorative apps	Light tiles, technical and architectural lighting	Flexible lighting elements
Printed RFID	Brand protection, e-ticketing	Logistics and automation	Item level tagging, EPC, identification
Printed Memory	Brand protection, identification, games	High end brand protection, advanced games	Electronics, multimedia
Organic Sensor	Photodiode, pressure temperature, chemical	Potentiometric sensor array	Intelligent sensor, embedded systems
Flexible Battery	Low capacity, discontinuous use	High capacity, continuous use	Direct integration into packaging systems
Smart Objects	Greeting cards, animated logos	Intelligent tickets, initial smart packaging	Complex smart packaging
Smart Textiles	Clothing keypads, sensors, light effects	Clothing integrated displays, photovoltaics	Fuel cells, fiber integrated sensors

Source: OE-A: Roadmap for organic and printed electronic applications

SLA Type Digital Fabrication

Type	Materials	X,Y-axis	Z-axis min μ m	Scale	Industry Apps	Run Cost $/ 1msq	Device MSRP $ x1000
MLS	Photopolymer	10µm, 10µm	50	1-5	1-6, 8, B, I, J	457	50
FTI	Photopolymer	768, 1024 dpi	102	1,2	1-6, 8, B, I, J	820	10

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Stereolithography (SLA)

- Stereolithography use 3-D CAD data to target laser emitting UV energy to fuse liquid photo-reactive resins materials and composites into solid cross-sections, layer by layer, to build three-dimensional parts
- First solid state stereo-lithography system 1996
- 75%+ of additive digital fabrication uses SLA technology

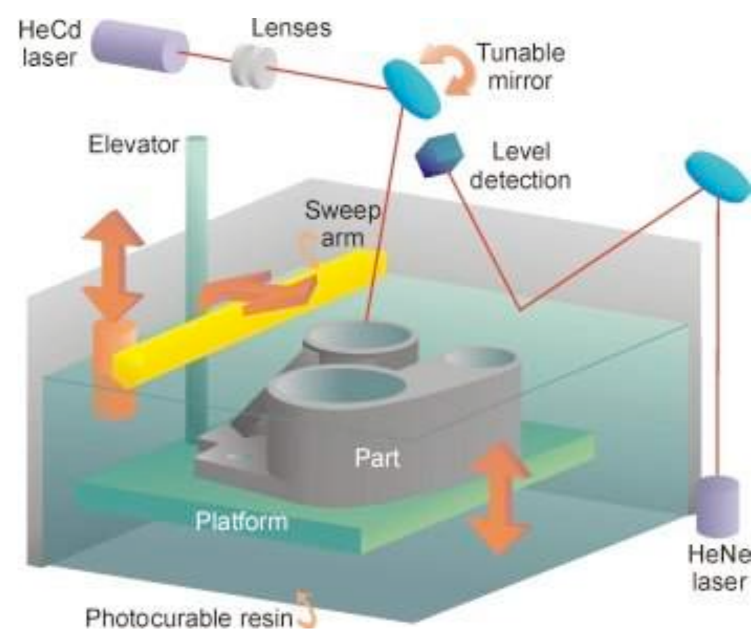

Image source: Princeton University Ceramic Materials Laboratory

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SLA

- 3D Systems – iPro
- DWS Systems Srl - Digital Wax
- Envision Technologies GmbH
- MicroTEC
- F&S Stereolitho-graphietechnik GmbH
- Autostrade Limited
- Sony Precision Technology,
- Teijin Seiki/CMET
- D-MEC
- Denken Engineering
- Laser Solutions
- Unirapid
- Meiko

Picture source: http://www.alexdenouden.nl/08/rapprod2.htm

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SLA Applications & Limitations

- Concept development
- Design validation
- Form and fit analysis
- Molding and casting patterns
- Wax forms for jewelry casting
- Dental forms
- Architectural models
- Some machine molds & parts

- Limited to prototypes, models, casting forms, and small plastic products
- Limited to photopolymers available for process
- Some finishing limitations
- Slow production process

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Micro Stereolithography (MSL)

- Like standard stereolithography, MSL forms 3-D items through layer-on-layer coating and laser UV curing photopolymer resins
- MSL, however, uses very fine resin solids that provide layers as thin as one µm
- Features as small as 5 µm have been demonstrated

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Film Micro-Stereolithography (FMSL)

- FMSL uses a computer controlled digital mask in directing the cure of photopolymer resin into micro-lenses and micro-fluidic channels on flat or curved substrates, by accurately controlling exposure
- Georgia Tech group's work accounting for oxygen inhibition

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MSL Applications & Limitations

- D-MEC (Japan) Acculas Micro Laser Modeling System
- Master molds for nano-print lithography
- Projection Micro-Stereolithography (P μ SL)
- Micro Mechanical Electrical Systems (MEMS) prototypes
- MEMS devices

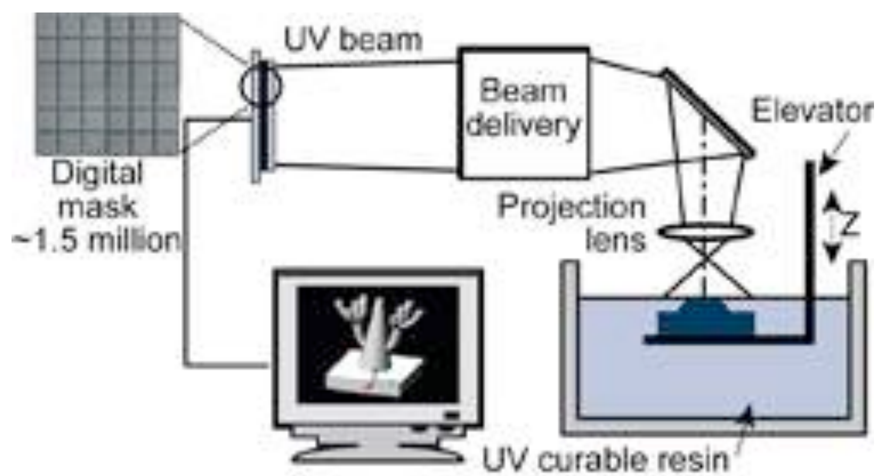

Diagram source: Lawrence Livermore National Laboratory

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Huntsman Digitalis (MLS)

- Huntsman's Araldite® Digitalis is an SLA type polymeric additive fabrication system that it calls MicroLightSwitch® MLS
- MLS can produce large numbers of parts simultaneously and selectively cure large photo-reactive resin surface areas at high speed with accuracy
- It employs a digitally controlled shutter system built into micro-electro mechanical systems (MEMS) chips
- Huntsman acquired CIBA, which developed UV-cure resins for and it SLA chemistry.
- MLS differs from SLA in that it can cure many points at once rather than a spot at a time with SLA
- The current unit exposes 40,000 pixels at a time
- Max. build: 650x370x600mm
- Max. resolution: x=10µm, y=10µm, z=50µm
- Head speed: 3-50 mm/sec

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Film Transfer Imaging (FTI)

- 3D Systems V-Flash (2007)
- Similar to SLA using a UV source to harden and cure photopolymer resin layer by layer, but inverts the vertical build action.
- The user installs a build pad facing down, upon which the model will attach and build, and a material cartridge that contains the film and resin build materials.
- CAD STL file instructs device for 3-D design
- V-Flash extracts resin from a reservoir and coats a film
- Build up pad descends onto the coated film
- System projects that layer's image onto the film
- UV light emanating from below the film selectively hardens the image
- Build pad lifts, repeats the film resin coating process
- Built pad and model-in-progress descends to the film for the imaging each subsequent layer

Photo source: 3D Systems

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FTI Applications & Limitations

- V-Flash
- Max. build space: 9"x6.75"x8"
- 228x171x203mm
- XY resolution of 768x1024 dpi

Photo source: 3D Systems

- Z layer thickness: 102 µm
- Discernable stair stepping artifacts
- Relatively low-cost, listing for under $10,000
- Accessible for hobbyist and product developers
- Useable in an office environment.
- Need to remove breakaway support elements
- They may leave residual burrs that require filing or sanding to remove

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Selective Laser Sintering (SLS)

- STL CAD file directs a laser to heat and fuse powdered materials
- Including polyamides, with or without fillers such as glass beads, carbon fibers and tool and stainless steel and steel alloys
- Laser bonds materials to form a thin layer
- Builds 3D objects layer-by-layer into functional products or parts

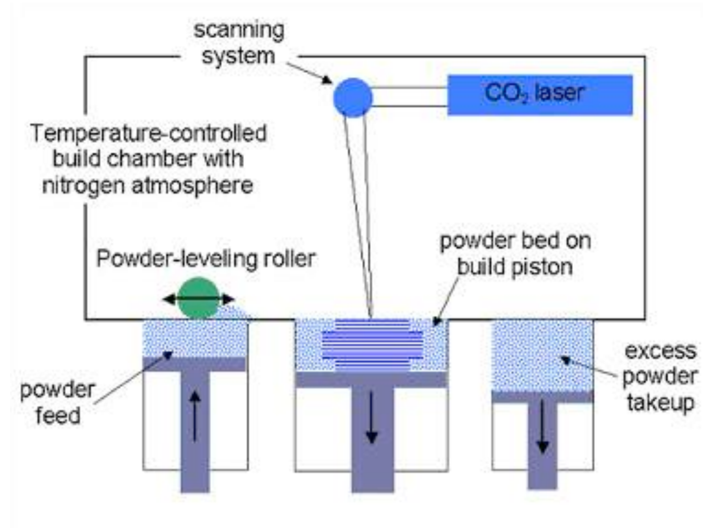

Diagram source: ttp://www.xpress3d.com/SLS.aspx

- 3D Systems: sPro line
- EOS GmbH Electro Optical Systems: EOSINT line

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SLS Applications & Limitations

- Uses a CO_2 laser to bond (sinter) powder
- Requires temperature controlled oxygen-free environment
- Typically nitrogen atmosphere
- powder leveling roller coats build piston after each scanning laser cure
- Can fuse small particles of ceramic, glass, plastic or metal
- Particle sizes typically about 50 µm in diameter.
- Direct selective laser sintering uses materials, such as metal powders without binders, that once sintered do not require post processing
- Indirect selective laser sintering employs binders with metallic and ceramic powders that require post processing, such as kiln heating, after sintering to create the finished item

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Selective Laser Melting (SLM)

- SLM is similar to SLS
- While SLS is used to fuse ceramic, glass and plastic in addition to metals, SLM is primarily employed to fuse metal powders
- Uses an ytterbium fiber high-powered laser to weld metal powders
- Powder layer thicknesses range from 20–100 µm

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SLM Applications & Limitations

- Not fused metal powder serves as support
- Produces fully dense metal objects from titanium, cobalt chrome, stainless & tool steel
- Dental, orthopedics, defense, aerospace and electronics industries use this technology.

- MTT Technologies Group of Staffordshire, UK: MTT SLM125 & MTT SLM250
- Both use argon gas build atmosphere.

Image source: renishaw.com

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Laser-Engineered Net Shaping (LENS)

- LENS uses a print head that moves in X, Y, and Z-axes with tilt and rotate, pitch and yaw options on some devices.
- High-intensity fiber laser light is focused through the print head to sinter metal powder as it exits the head and attaches to the target substrate in an atmosphere of inert gas to prevent oxygen from contaminating the process.

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LENS Applications & Limitations

- Defense & aerospace
- Energy industries
- Medical device manufacturers
- Repair and fabricate with titanium, nickel, cobalt, stainless steel and other alloys
- Optomec of Albuquerque, NM
- LENS MR7, LENS 750 & LENS 850-R
- LENS 850-R work area 900x1500x900 mm

- Produces fully dense metal objects
- Lacks support fillers, which can result in objects with excess material that require post-processing machining
- LENS also is termed Direct Metal Deposition (DMD)

Image source: Optomec

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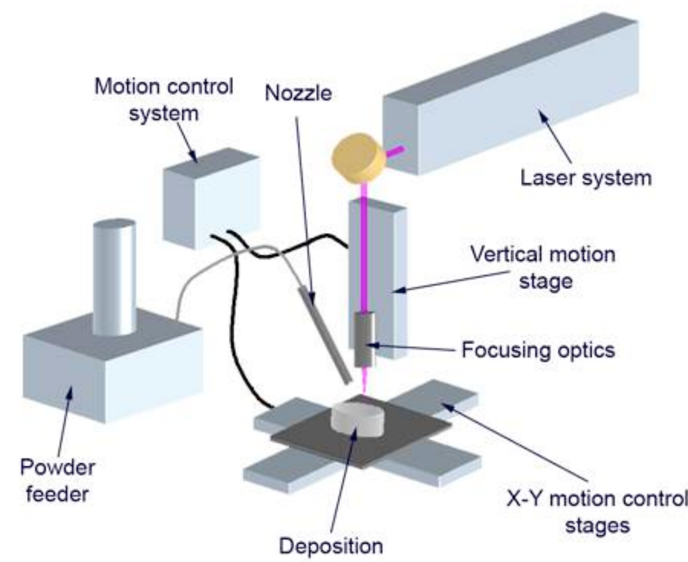
Laser Cladding (LC)

- LC typically deposits a powder on a surface, then a laser beam melts the powder to the surface
- Uses high power lasers including CO_2, Nd:YAG, diode, and fiber.
- LC is used to remanufacture worn surface, and to increase wear resistance of machine and equipment parts
- Clad material can also be introduced in a wire form
- LC process produces a 100% dense metal bond, fine microstructures, small heat affected zones (HAZ), and low distortion
- Low heat input process with minimal dilution of the base material for enhanced corrosion, abrasion, oxidation & wear resistance



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Fused Deposition Modeling (FDM)

- FDM is an additive digital fabrication process that melts, extrudes and deposits layers of thermoplastic polymer from a coil.
- Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polypropylene (PP), High-density Polyethylene (HDPE), Low-density Polyethylene (LDPE), Un-plasticized Polyvinyl Chloride (uPVC)
- Polycarbonate (PC), Polyphenylsulfone (PPSF/PPSU)

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FDM Applications & Limitations

- Stratasys: FORTUS 360mc, 400mc & 900mc; Dimension uPrint, uPrint Plus, Elite, BST & SST
- 3D Systems' Bits From Bytes: BFB 3000 Plus & RapMan 3.1 kit
- MakerBot: Thing-O-Matic & Cupcake.

- Thermopolymer not photopolymer
- Stratasys: 127-178 µm layer
- BFB: 125 µm layer
- MakerBot: over 100 µm layer

Image, Bell Helicopter. Source: Stratasys

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Electron Beam Melting (EBM)

- EBM uses an electron beam to melt metal powder in a layer-by-layer build
- Build occurs in a vacuum enclosure to prevent oxidation & other chemical reactions
- EBM typically first scans the metal powder bed to produce optimal elevated temperature for alloy being melted
- Then melts build item's contours & lastly, its interior mass
- EBM does not use mirrors or other optics, like SLA, SLS and SLM

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EBM Applications & Limitations

- Elevated & even temperature build environment
- Results in stress-relieved parts
- Material properties comparable to wrought metals
- Electromagnetic coils control e-beam
- High precision control without optical diffusion
- Fast build process
- Can use deflection electronics to melt multiple locations simultaneously
- High capital & operations cost

EBM Applications & Limitations

- Titanium alloys, Ti with aluminum, zirconium, niobium, tantalum, nickel and cobalt
- Fully formed & dense
- No post processing required
- Medical implants
- Aerospace & automotive parts & castings

- Arcam AB, of Gothenburg, Sweden,
- A1for implants
- A2 for large industrial parts
- High capital cost
- Limited build size of 20x20x35 centimeter
- 0.2 to 1.0 mm beam spot diameter
- Limited to use with metal powders

Photo source: Arcam.com

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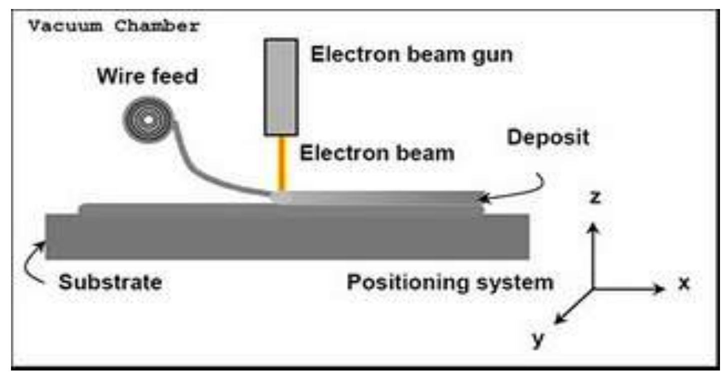
Electron Beam Freeform Fabrication (EBF^3)

- Wire feed to E-beam melt and deposit
- Titanium, nickel, stainless steel, refractory alloys
- Can vary alloy and chemistry types throughout the formed item component to vary strength, fatigue performance, & toughness
- Eliminates machining steps
- Can provide hybrid structures with lugs and bosses without high fault zones associated with castings
- Sciaky EB3F



Photos & diagram source: NASA

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EBF³ Applications & Limitations

- NASA's Langley Research Center in Hampton Roads, Virginia developed EBF3

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3-D Inkjet (3DIJ)

- Fine line between digital printing & fabrication
- Decoration vs. function
- Build layer upon layer
- Etch layer
- Phase change inkjet (thermoplastic) Solidscape
- UV cure photo polymer (3D Systems, Objet)
- Binder + Aggregate (Z-Corp/ HP heads)
- E-beam cure polymer
- MicroFab
- MicroDrop
- Seiko Epson
- Electronics, PV, RFID
- Phase change print heads:
  - Fujifilm Dimatix
  - Nextjet
  - Ricoh
  - Trident
  - Xerox (Tektronix)

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PolyJet Matrix

- Objet Connex™ PolyJet Matrix
- 8 print heads, 96 50-micron diameter nozzles per head
- Each material uses two print heads
- Material deposit synchronized
- Uses multiple Objet FullCure® acrylic-based photo polymer model materials
- Permits printing of materials of varying hardness, tensile strength, elongation, response to heat, flexibility and color in one simultaneous build
- 600x600 dpi

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Robo-casting (RC)

- Robo-casting uses computer-controlled deposition of ceramic slurries -- mixtures of ceramic powder, water, and trace amounts of chemical modifiers -- through a syringe, which deposits the material in thin layers on a heated base.
- Less expensive and faster fabrication of complex parts
- Syringe deposited materials include: silica, alumina, lead zirconate titanate, hydroxyapatite colloidal particles, polymeric, metallic, and semiconducting colloidal inks

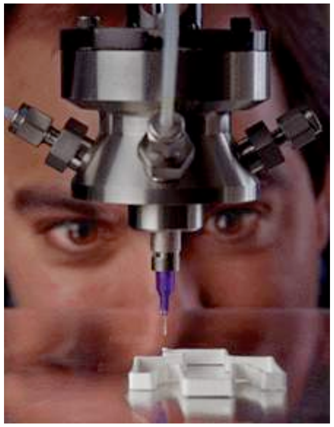

Photo source: http://www.sandia.gov (photo: by by Randy Montoya)

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Shape Deposition Manufacturing (SDM)

- Shape Deposition Manufacturing combines additive and subtractive methods, alternately depositing and shaping or machining layer of part and support materials to both fabricate and assemble items.
- SDM permits access to formed product's internal geometry
- Enables embedding of actuators, sensors and other components
- Can vary deposited materials and property characteristics of product

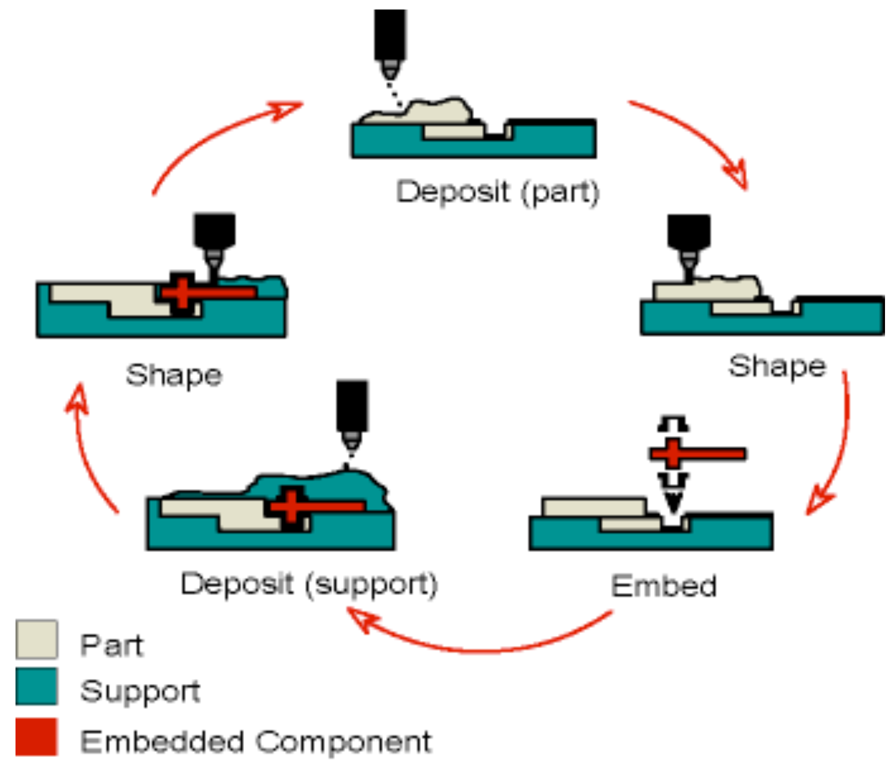

Diagram source: http://www-cdr.stanford.edu/biomimetics/sdm.html

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Laminated Object Manufacturing (LOM)

- LOM developed by Helisys Inc., now Cubic Technologies
- LOM laminates sheets of paper, plastic or metal with a heated roller; a laser traces the desired object shape and cross hatches waste areas for each layer
- No chemical reactions involved
- Useful for large object
- Paper based models have wood-like character
- Relatively low cost

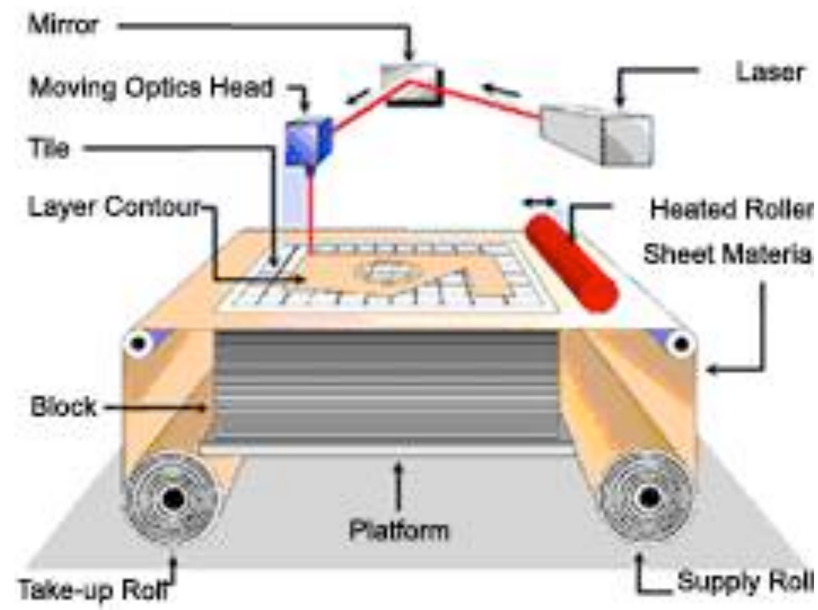

Diagram source: http://www.rpc.msoe.edu

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Solid Ground Curing (SGC)

- The now defunct Cubital Inc. of Ra'anana, Israel developed Solid Ground Curing (SGC), aka, the Solider Process
- Objet now owns IP for this process
- SGC system generates laser exposed photo masks for each layer
- Sprays a layer of photosensitive resin
- Places the mask for that layer in between the UV light source and the sprayed surface
- Opens the lamp shutter exposing the whole layer at once hardening it
- Removes the mask & a vacuum removes the uncured polymer
- Roller coats wax into the cavity left by the removed resin for build support
- The whole resin and wax layer is then milled and the debris vacuumed away
- The SGC system then repeats the process for each layer.

SGC Applications & Limitations

- Large parts, 500×500×350 mm (20×20×14 in)
- More expensive and less accurate than SLA
- Process creates much waste materials

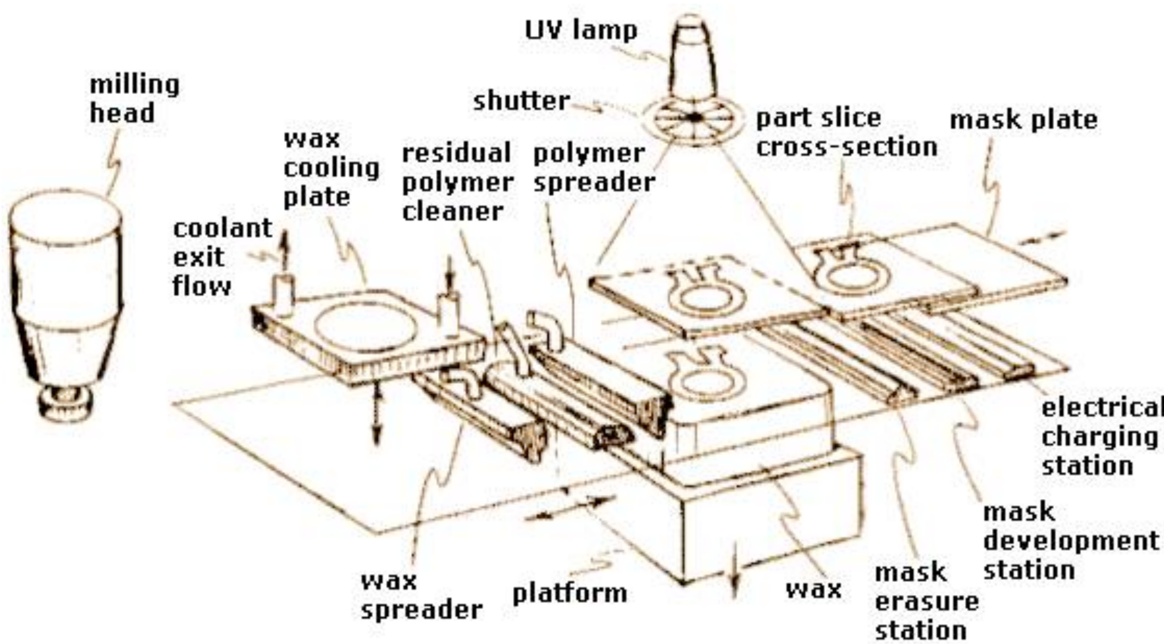

Diagram source: http://www.efunda.com

Ultrasonic Consolidation (UC)

- Also known as Ultrasonic Additive Manufacture (UAM)
- Patented by Dawn White
- Formed Solidica in 1999
- Formation machine

Image source: Solidica

- UC employs high frequency (about 20 kHz) sound to weld metal foils held under pressure together. It uses subtractive CNC milling to contour each layer
- Joins dissimilar metals of different thicknesses
- Embeds fibers and inserts electronic parts

UC Applications & Limitations

- DuraTi: Titanium Aluminide laminate material ($TiAl_3$)
- Graduated Modulus Energy Absorbing Material (GMEAM)
- Military
- Sensor embedding
  - Fiber optic sensors
  - RFID chips

- Low temperature
- Engineered structure
- No laser or e-beam
- 1.5-3 kW
- 100 to 200 μm thick foils

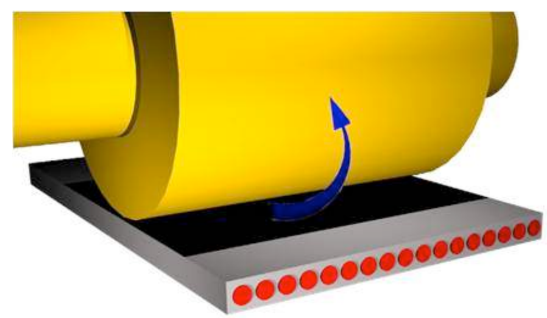

Image source: Solidica

Very High Power Ultrasonic Additive Manufacturing (VHP UAM)

- Edison Welding Institute (Columbus, OH) and Solidica
- 9.0 kW push-pull ultrasonic system weld materials such as Ti 6-4, 316SS, 1100 Cu & Al7075
- Dual 4.5 kW transducers
- Can fabricate parts up to1.8mx1.8mx0.9m
- As compared with UC: fewer weld voids, faster processing, able to weld advanced materials

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Selective Area Laser Deposition (SALD)

- Laser-driven, gas-phase based SFF technique for joining together ceramic components with ceramic filler material
- Used to join silicon carbide tubes with silicon carbide from a gas phase reaction. Can employ one or multiple laser beams. A gas environment of tetramethylsilane and hydrogen used as deposition precursors.

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Cold Metal Transfer (CMT)

- Fronius
- Alternates hot & cold operation with wire movement for
- Primarily low energy digital welding method
- Placement controlled either robotically or manually
- Welds without root-side drop-through
- Spatter-free brazing
- Joins aluminum & steel, light gauge from 0.3mm
- Lower energy consumption & hazard fumes/vapors relative to MIG & MAG

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Integrated/Precision Extrusion Deposition (IED)/(PED)

- 3D fabrication of biological matrix for digital organ reproduction
- CAD/CAM controls extrusion to precisely fabricate internal and external biological scaffold architecture, porosity, pore size, & interconnectivity
- Integrated AC cooling device permits use of biopolymer with melting points to 250°C
- Drexel University patent PED

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IED/PED Applications & Limitations

- Some cells prefer scaffolds built from stiff material
- Stiff materials tend to melt at high temp.
- PED with an integrated Assisting Cooling (AC) device enable uses of high melting biopolymer for building biological scaffolds
- AC device is mounted at the nozzle of the PED at four NSEW XY cooling points
- AC uses nitrogen, compressed air, & water to cool polymer as it is extruded from the PED

VCE Solutions

Near Field Electro-spinning (NFES)

- Near-field electro-spinning (NFES) is a process that deposits solid nanofibers in a direct, continuous, and controllable manner. A tungsten electrode with tip diameter of 25 micrometer is used to construct nanofibers of 50-500 nm line width on silicon-based collectors while the liquid polymer solution is supplied in a manner like that of a dip pen. The minimum applied bias voltage is 600 V, and minimum electrode-to-collector distance is 500 microns to achieve position controllable deposition. Charged nanofibers can be orderly collected, making NFES a potential tool in direct write nanofabrication for a variety of materials.

VCE Solutions

Low Voltage NFES (LV NFES)

- A continuous method for controlled electro-spinning of polymeric nanofibers on two-dimensional (2D) and three dimensional (3D) substrates using low voltage near-field electro-spinning (LV NFES).
- The method uses a super elastic polymer ink formulation that enables continuous electro-spinning at a very low voltage of 200 V, much lower than conventional NFES, thereby reducing bending instabilities and increasing control of the polymer jet.
- In one application, polymeric nanofibers are freely suspended between microstructures of 3D carbon on Si substrates to illustrate wiring together 3D components in any desired pattern.

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LV-NFES Applications & Credits

- Electrospun nanofiber based wiring of structural and functional components in MEMS, microelectronics, optoelectronics, and sensor devices.
- Advanced fabrics
- Bio-mimicry for scaffolds in tissue engineering.
- Specialized polymeric nanofibers customized patterning
- University of California, Irvine
- **Inventors**
- Bisht, Gobind S.
- Canton, Giulia
- Madou, Marc J.
- Mirsepassi, Alireza
- Rankin, Derek D.

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Bio-fabrication (BF)

- Gabor Forgacs of the University of Missouri and Glenn Prestwich, a chemist at the University of Utah-Salt Lake City research on building vasculature
- Anthony Atala, MD Urologist, developed printed organs, particularly bladders, with patient's DNA
- Robert Nerem, director of the Parker H. Petit Institute for Bioengineering and Bioscience at Georgia Tech
- Doris Taylor at the University of Minnesota created a functional rodent heart
- Cytograft Tissue Engineering creates vasculature with lab cultured sheets of tissue, which it rolls over a rod to form a tube.

Solutions

Printing Skin

- Wake Forest Institute for Regenerative Medicine
- Weixin Zhao et al demonstrated rapid healing of burns in animals using an inkjet printer with cartridges full of living tissue
- Cosmetic and pharmacology testing can also use inkjet printed skin instead of animal testing

VCE Solutions

Inkjet Printing Skin

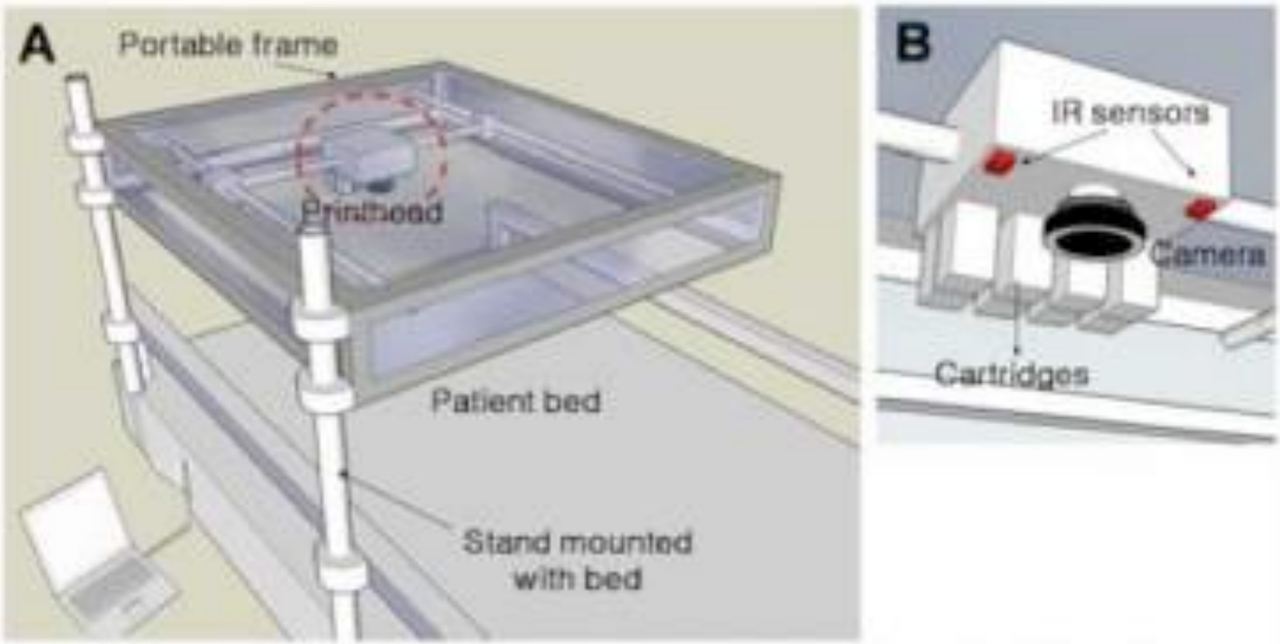

Figure 1. Schematic drawing of the proposed portable skin bio-printer (A) and close-up of the printhead (B).

Image source: Wake Forest University

D_Shape, Monolite

- Resolution: 4 to 25 dpi
- Nozzles: 300 at 20mm interaxis
- 6m x 6m format
- Sand, stone dust, inorganic magnesium-based binder

- Sculpture
- Large 3D stone-like objects
- Buildings
- Bus stops; park benches/ seats; kiosks; colored marble effect pavements; fountains.
- Staircases; flower boxes; home stone furnishing: basins, kitchens, sofas, tables

Images' source: Monolite UK Ltd.

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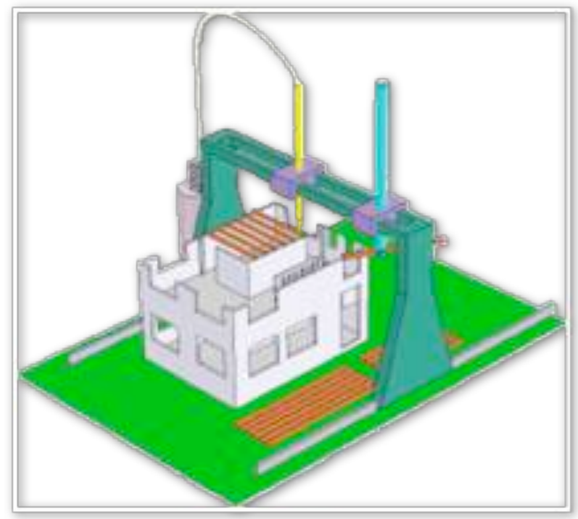
Contour Crafting

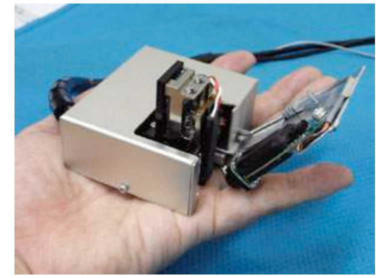
- Dr. Behrokh Khoshnevis
- University of Southern Californ
- National Science Foundation
- Caterpillar Inc
- USG
- Printing buildings



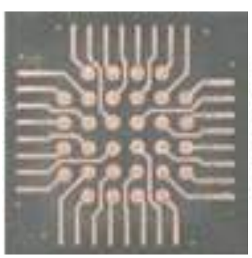
Images Sources: nextbigfuture.com & contourcrafting.org

VCE Solutions

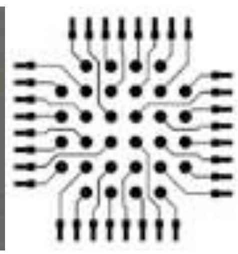
AIST Super-fine Ink-jet SIJ



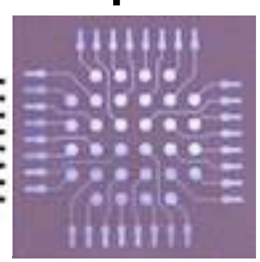
- SIJ Technology Japan
- DC 5 volt power source
- Jet particles < 20nm
- 1/1,000 of 2pL drop
- Super-fine metal particles melt at much lower temp.



Conventional IJ



Cad Drawing



Super-fine IJ

- Micrometer scale printing
- Maskless precision patterns
- Electro-conductive polymers
- Functional ceramics
- Carbon nanotube
- Super fine wire patterning

VCE Solutions

Rapid Prototyping Systems I

- Stereolithography (SLA) and Selective Laser Sintering (SLS), 3D Systems, Inc., Rock Hill, SC
- Solid Creation Stereolithography, Sony Manufacturing Systems Corporation, Saitama, Japan
- Solid Imager Stereolithography, Aaroflex, Inc., Fairfax, VA
- Rapid Meister Stereolithography, CMET Inc., Yokohama, Japan
- Realizer Stereolithography, Realizer GmbH, Borchen, Germany.
- Small scale stereolithography, Unirapid Inc., Misato, Japan
- Laser Sintering of metals and plastics, EOS GmbH, Munich, Germany
- E-Darts desktop SLA system, Autostrade Co. Ltd, Oita City, Japan
- Fused Deposition Modeling (FDM), Stratasys, Inc., Eden Prairie, MN
- Paper Lamination Technology, KIRA Corporation, Aichi, Japan

VCE Solutions

Rapid Prototyping Systems 2

- Laminated Object Manufacturing (LOM), Cubic Technologies Inc., Carson, CA
- Three dimensional plotting, Solidscape Inc., (formerly Sanders Prototype Inc.), Merrimack, NH
- Digital Light Processing (DLP)Envision Technologies GmbH, Gladbeck, Germany.
- Polyjet, photopolymer-jetting technology, Objet Geometries Ltd, Rehovot, Israel.
- Z810 Ink Jet Printer, Z Corporation, Burlington, MA (Z Corporation is a subsidiary of Contex of Denmark)
- HTS FDM machine and LTY 3D printer, Fochif Mechatronics Technology Co., Ltd, Shanghai, China
- Patternless Casting Modeling(PCM), Stereolithography and Fused Deposition Modeling, Beijing Yinhua Co. Ltd, Beijing, China

VCE Solutions

Direct Manufacturing Systems

- LaserCusing, Concept Laser GmbH, Lichtenfels, Germany
- Direct Metal Laser Sintering (DMLS), EOS GmbH, Munich, Germany
- High Precision Ink Jet Manufacturing, Fcubic AB, Molndal, Sweden
- Laser Engineered Net Shaping (LENS), Optomec Design Company, Albuquerque, NM
- Electron Beam Melting (EBM), Arcam AB, Molndal, Sweden
- Direct Metal Deposition (DMD), POM Group Inc., Auburn Hills, MI
- Direct Metal Printing, ProMetal, Irwin, PA
- Selective Laser Melting (SLM), Realizer GmbH, Borchen, Germany
- Direct Shell Production Casting (DSPC), Soligen Inc. of Northridge, CA

VCE Solutions

Concept Modeling Systems

- The InVision - series 3D printers and V-Flash desktop printer by 3D Systems, Inc. of Rock Hill, SC
- Dimension 3D printers by Stratasys, Inc. of Eden Prairie, MN
- RapidPro - a low cost rapid prototyping system (manually assembled LOM) by Boxford Limited, Wheatley, UK
- SD series 3D printers, Solidimension, Ltd., Rosh Ha-Ayin, Israel
- ZPrinter 310 Plus & Spectrum Z510, Z Corporation, Burlington, MA (subsidiary of Contex of Denmark)
- VX800 3D printer, Voxeljet Technology GmbH, Augsburg, Germany
- DESIGNmate Mx & Cx, 3D printers, Contex, Alleroed, Denmark
- Desktop Factory, Pasadena, CA, low cost desktop 3D printer

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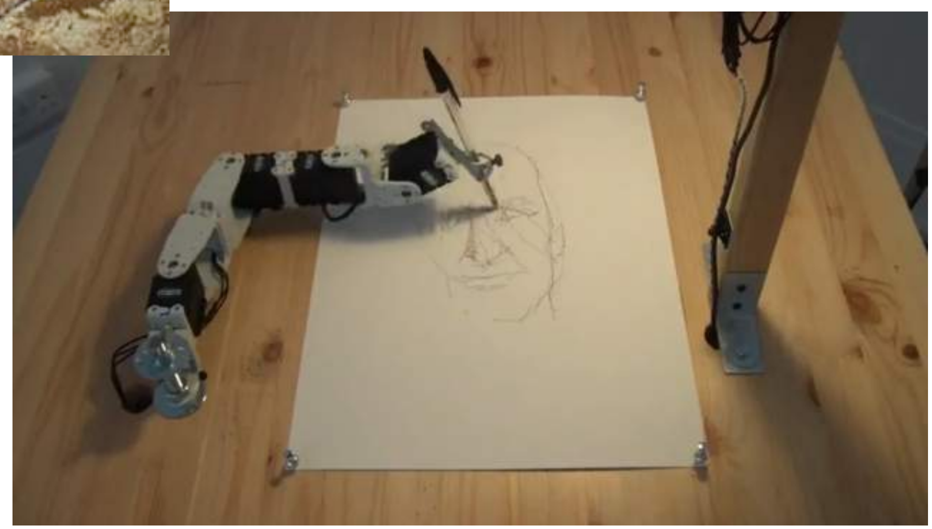
Cave to Digital Fabrication



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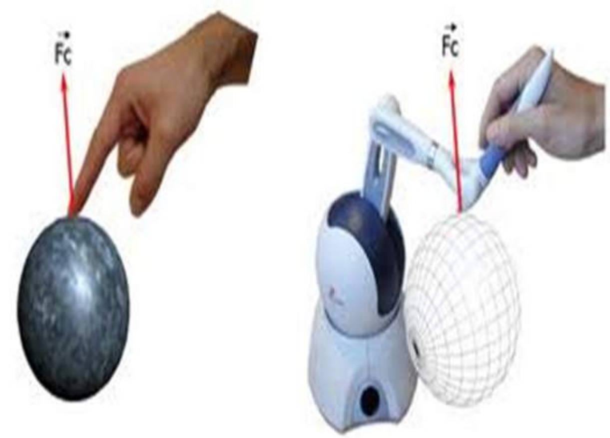
Human Interface: Haptic Tools

Haptic tools: provide users with tactile feedback and stimulation through vibration, motion or force and enable communication of intent



- Users can employ haptic devices to create virtual objects for computer simulation and to control virtual objects and physical devices for processes such as digital printing and fabrication

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Meaning

- Challenge
- “Techniques such as advanced robotics and nanotechnology simply must be taken seriously, because on their own, and in combination with genetic engineering, they could quickly evaporate human meaning.” Bill McKibben, *Enough, Staying Human in an Engineering Age*

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Our Economic Situation

"Instability is an inherent and inescapable flaw of capitalism." Hyman Minsky

Ben Bernanke, Federal Reserve Chairman said last week that unemployment is a "national crisis," with so many workers among the long-term unemployed that the economy is at risk of suffering long-run as well as short-run damage.

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Issues

- 31Oct 2011: 7 billion people, UN estimate
- 8 billion by 2027, 9 billion by 2046 (USCB)
- Digital fabrication will eliminate assembly & manual fabrication jobs & careers
- National Center for Manufacturing Science projects 98% of manufactured products will be digitally designed and fabricated by 2020
- Projected digital fabrication jobs require greater numbers of skilled personnel than available
- Economy is facing a skill and demand gap

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Opportunities

- Low cost 3-D manufacturing systems, e.g. MakerBot, V-Flash, & BFB stimulate development of digital manufacturing
- Distribute design, print and manufacture
- Energy production with thin film PV
- Electronics, LCD, PLED displays
- Manufacture of genetically compatible body parts

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Conclusions 1

- Digital technology will both complement and, for some applications, replace traditional printing and fabrication methods
- Digital fabrication technologies can bring manufacturing closer to market and reduce transportation related expenses and delays
- Digital fabrication can create products and services that respond to the needs of both web and traditional marketing: web-to-manufacture

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Conclusions 2

- Need for mentoring
- Training of CAD designers and STL generators
- Need to eliminate economic imbalance & instability

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Thank You

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