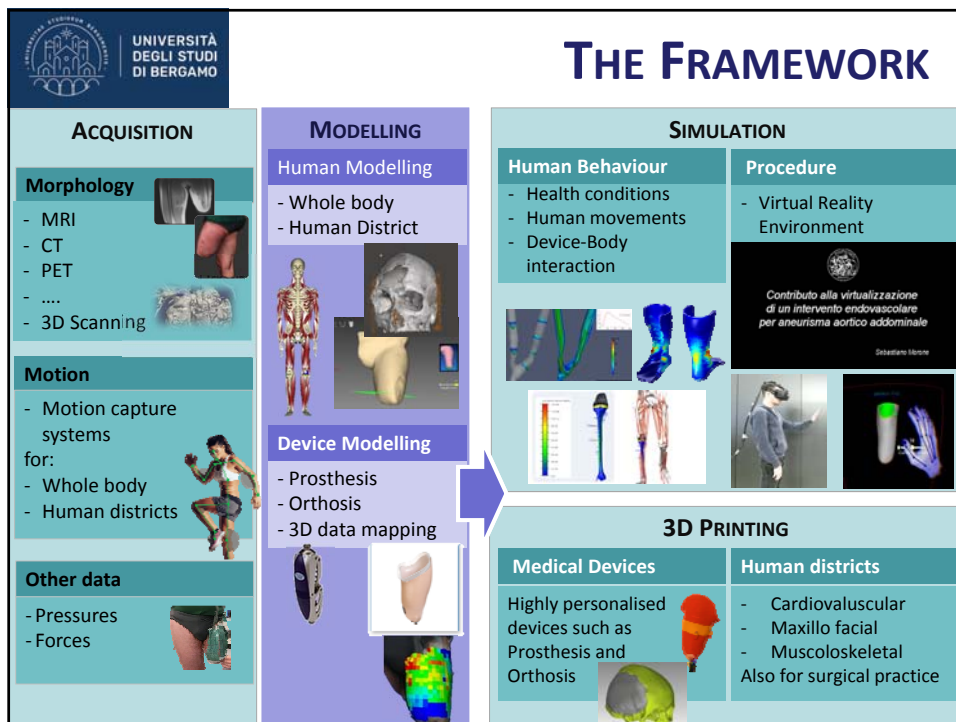



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 Dipartimento di Ingegneria Gestionale, dell'Informazione e della Produzione

DIGITAL HUMAN MODELLING ADDITIVE MANUFACTURING




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CONTENTS

3D PRINTING


- FROM 3D MODEL TO THE PHYSICAL OBJECT
- TECHNOLOGIES
- EXAMPLES

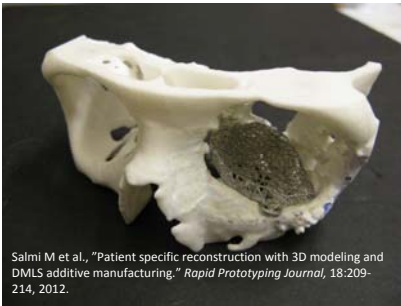
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UNDERLYING CONCEPT


- 3D OBJECTS ARE CREATED BY ADDING LAYER-UPON-LAYER OF MATERIAL, WHETHER THE MATERIAL IS PLASTIC, METAL OR MAYBE ONE DAY... HUMAN TISSUE
- STARTING FROM THE 3D GEOMETRIC MODEL
 - THE PHYSICAL PROTOTYPE CAN BE AUTOMATICALLY GENERATED





Salmi M et al., "Patient specific reconstruction with 3D modeling and DMLS additive manufacturing." *Rapid Prototyping Journal*, 18:209-214, 2012.


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HISTORY

- 1980:** FIRST PATENT FILED FOR RAPID PROTOTYPING BY DR. KODAMA IN JAPAN
- 1986:** CHARLES HULL ISSUED PATENT FOR SLA
- 1989:** SCOTT CRUMP INVENTED AND PATENTED FDM (FUSED DEPOSITION MODELLING) TECHNOLOGY THAT WAS COMMERCIALIZED BY HIS COMPANY STRATASYS
- MID-1990s:** METAL PRINTING TECHNOLOGIES WERE STARTING TO COME INTO THEIR OWN
- 2005:** ADDITIVE TECHNOLOGY PATENTS WERE STARTING TO EXPIRE


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MAIN FIELDS OF APPLICATION

12.1% AEROSPAZIALE	19.5% AUTOMOBILISTICO	15.1% MEDICALE
 General Electric	 Ford	 Invisalign
 Boeing	 BMW	 Organovo


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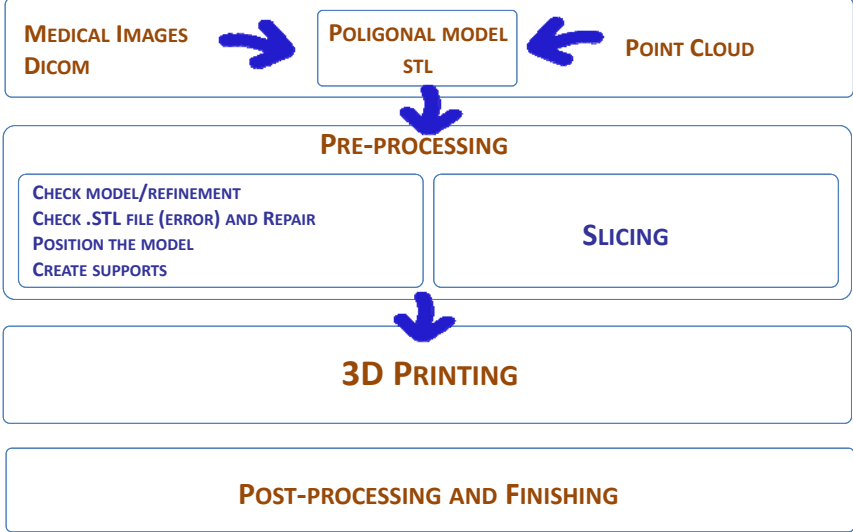
MEDICAL APPLICATIONS

- **PRE-PROCEDURAL PLANNING/SIMULATION**
- **PATIENT CONSULTATION**
- **MEDICAL DEVICES**
- **MEDICAL EDUCATION**
- ...

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HOW TO PRINT



```
graph TD; A[MEDICAL IMAGES  
DICOM] --> B[POLIGONAL MODEL  
STL]; C[POINT CLOUD] --> B; B --> D[PRE-PROCESSING]; subgraph D; D1[CHECK MODEL/REFINEMENT  
CHECK .STL FILE (ERROR) AND REPAIR  
POSITION THE MODEL  
CREATE SUPPORTS]; D2[SLICING]; end; D --> E[3D PRINTING]; E --> F[POST-PROCESSING AND FINISHING];
```

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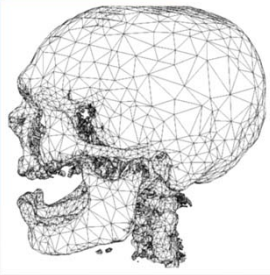
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INPUT DATA


- APPROXIMATE REPRESENTATION OF THE OBJECT BY A TRIANGLE MESH
- STL (.STL) FORMAT INTRODUCED BY 3D SYSTEMS IN 1987

Example STL file in ASCII

```
Solid example
  facet normal 6.89114779e-2 -9.96219337e-01 -5.28978631e-02
    outer loop
      vertex 2.73239994e+01 1.08957005e+01 4.57905006e+01
      vertex 2.81019993e+01 1.09582005e+01 4.56250000e+01
      vertex 2.75955009e+01 1.09116001e+01 4.58456993e+01
    endloop
  endfacet
  :
  :
endsolid example
```




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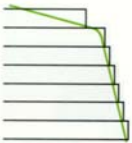
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SLICING

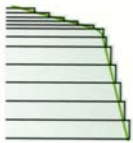
- THE SLICING IS A CRITICAL OPERATION BECAUSE IT DETERMINES THE PRECISION OF THE PROTOTYPE IN A DECISIVE WAY...



- TWO OPTIONS
 - **UNIFORM SLICING:** LAYERS OF CONSTANT THICKNESS
 - **ADAPTIVE SLICING:** THE THICKNESS IS CHOSEN ACCORDING TO THE SURFACE CURVATURE, TO MINIMIZE THE STEPPED APPEARANCE OF THE EXTERNAL SURFACE



UNIFORM



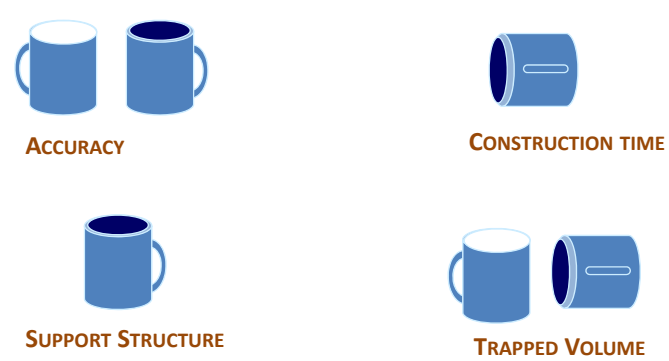
ADAPTIVE

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POSITION THE MODEL

■ **KEY ISSUES**



ACCURACY

CONSTRUCTION TIME

SUPPORT STRUCTURE

TRAPPED VOLUME

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TECHNOLOGIES (1/2)

PROCESS

- PHOTOPOLIMERIZATION
- SINTERING
- SPRUZZATURA
- GLUEING
- EXTRUSION
-

MATERIALS

- RESINS-PHOTOPOLYMERS
- THERMOPLASTIC
- CERAMIC AND METALLIC POWDERS
- PAPER SHEET
- PLA-ABS
-

THE ACCURACY OF THE OBJECTS OBTAINABLE WITH THESE TECHNOLOGIES IS CURRENTLY OF 1/10 MILLIMETER ON THE Z AXIS

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TECHNOLOGIES (2/2)

UNIFIED TERMINOLOGY (ASTM-APPROVED)

1. **VAT PHOTOPOLYMERIZATION (STEREOLITOGRAPHY)**
2. **MATERIAL EXTRUSION (FDM)**
3. **POWDER BED FUSION (SINTERING)**
4. **BINDER JETTING (3D PRINTING)**
5. **MATERIAL JETTING (POLY/MULTI-JET)**
6. **SHEET LAMINATION (LOM)**
7. **DIRECT ENERGY DEPOSITION (ELECTROBEAM MELTING)**

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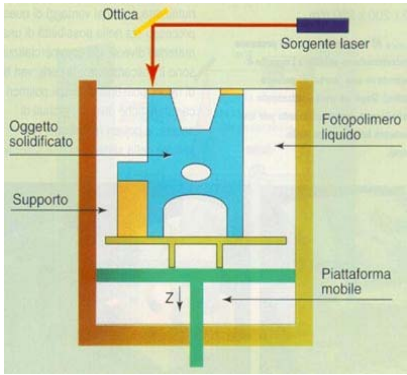


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VAT PHOTOPOLYMERIZATION (STEREOLITOGRAPHY)

- **IT HAS BEEN THE FIRST TECHNOLOGY TO INTRODUCE THE LAYER BY LAYER APPROACH**
- **THE FIRST LABORATORY DEMONSTRATIONS IN 1984**
- **THE FIRST SYSTEM AVAILABLE ON THE MARKET AT THE END OF 1988**
- **BASED ON PHOTOPOLYMERIZATION**


- **SUPPORTING STRUCTURES NEEDED**
- **REQUIRES MANUAL REMOVAL OF LATTICE SUPPORTS, CHEMICAL CLEANING AND POST CURING**

(IMMAGINE ©1997, 1998 PROTOTIPAZIONE RAPIDA, PUBLITEC)

- **SUGGESTED APPLICATIONS: CMF, ORTHOPEDIC AND VASCULAR ANATOMICAL MODEL**

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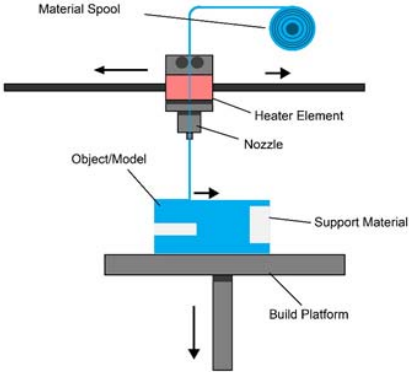


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MATERIAL EXTRUSION (FDM)

- **BASED ON THE EXTRUSION OF THERMOPLASTIC MATERIALS**
- **DEPOSITION OF LAYERS OF MATERIAL HEATED UP TO THE MELTING TEMPERATURE**

- **SUPPORTING STRUCTURES NEEDED**
- **VISIBLE LAYERS**



- **SUGGESTED APPLICATIONS: DEVICES PROTOTYPE, ORTHOPEDIC AND CMF ANATOMICAL MODEL**

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LOW-COST TECHNOLOGIES

- **MAINLY BASED ON FDM TECHNOLOGY**
 - WIDESPREAD CONSTRUCTION SOLUTIONS
 - LOW MACHINE COSTS (0.5 - 3 K €)
- **MATERIALS**
 - PLASTIC: MOST COMMON ARE ABS OR PLA
- **APPLICATION FIELDS**
 - THE REDUCED DIMENSIONS AND THE MATERIALS USED LIMIT THEM TO THE CREATION OF PROTOTYPES FOR THE CONCEPT PHASE
- **PRO (IN ADDITION TO THE COST)**
 - EASY TO USE
 - REDUCED PRINTER SIZE
 - NO POST-PROCESSING
 - LIMITED MAINTENANCE
- **CONS**
 - REDUCED VOLUMES OF CONSTRUCTION
 - LIMITED RESOLUTION





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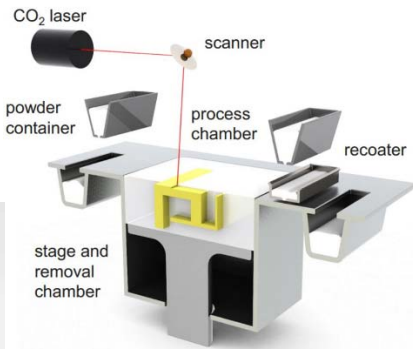
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POWDER BED FUSION (SELECTIVE LASER SINTERING)

- **BASED ON DIRECT SINTERING OF POWDERS BY LASER**
- **NO SUPPORTING STRUCTURES**
- **STERILIZABLE**
- **HIGHLY DURABLE**

- **CREATES DUST DURING CLEANING**






<http://www.custompartnet.com/wu/images/rapid-prototyping/sls.png>

- **SUGGESTED APPLICATIONS: CMF ORTHOPEDIC ANATOMICAL MODELS, SURGICAL GUIDE AND IMPLANTS**

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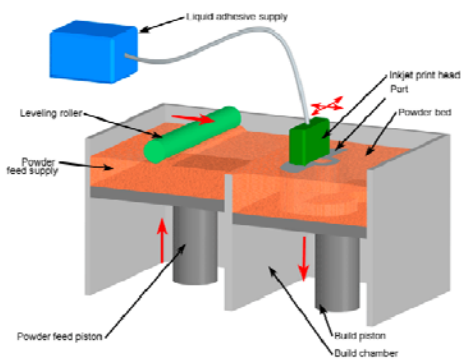


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BINDER JETTING

- **DEPOSITION OF A BINDER ON LAYERS OF POWDERS (CERAMICS, CELLULOSE AND METAL)**
- **DEVELOPED AT MIT AND FIRST SYSTEM WAS Z402 BY Z-CORP**
- **NO SUPPORTING STRUCTURES**
- **MULTICOLOR**


- **CREATES DUST DURING CLEANING PROCESS**
- **BRITTLE MATERIAL**



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- **SUGGESTED APPLICATIONS: VARIOUS ANATOMICAL MODELS WITH CUSTOM STRUCTURES**

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MATERIAL JETTING (POLY/MULTI-JET)

- **DIRECT MATERIAL DEPOSITION**
- **DERIVED FROM INK-JET TECHNOLOGY**
- **MULTICOLOR**
- **MULTI MATERIAL**

- **HIGH Z**
- **POST PROCESSING**


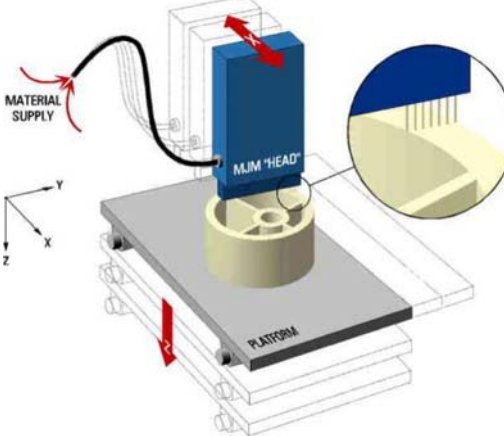



IMAGE COURTESY OF STRATASYS



- **SUGGESTED APPLICATIONS: CARDIAC AND SOFT TISSUE ANATOMICAL MODEL**

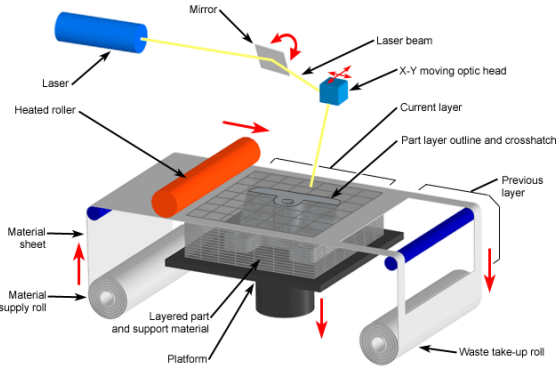
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SHEET LAMINATION – LOM

- **BASED ON THE OVERLAP OF SHAPED SHEETS**



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DIRECT ENERGY DEPOSITION (ELECTROBEAM MELTING)

- METAL MELTING PROCESS



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